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MODELLING CORROSION AND DEUTERIUM PICKUP IN OPERATING REACTOR PRESSURE TUBES

No 86-151-K

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ABSTRACT

A data base has been established consisting of all data on oxide thicknesses and deuterium concentrations in the body of pressure tubes removed from Ontario Hydro CANDU reactors. A methodology has been developed to analyze the data, construct an empirical model of corrosion and deuterium pickup, and predict equivalent hydrogen levels in the body of operating Zr-2.5 wt% Nb pressure tubes by 1990. These predictions are required in order to assess pressure tube response following contact with the calandria tube (TRAC), and to assist in the decision-making process for spacer location and repositioning (SLAR). This report provides comprehensive documentation of all work to date. A more succinct review may be found in the recent Proceedings of the Fuel Channel Technology Seminar (to be published). There is a 95% probability that by 1990, assuming initial hydrogen levels of 10 ppm, equivalent hydrogen levels in the body of Pickering 3 and 4, and Bruce 2 pressure tubes will not exceed 21 ppm. For Bruce 3 and Pickering 5 pressure tubes (based on similar behaviour to pressure tubes in Pickering 3 and 4, and Bruce 2), by 1990, equivalent hydrogen levels should not exceed 21 ppm and 14 ppm respectively. These predictions which are based on limited data from examinations of a small number of pressure tubes relative to the total population, are valid only for the portion of the pressure tubes for which contact with the calandria tube is predicted. The methodology developed will be used to improve the corrosion model and confidence in predictions, as more data becomes available from removed pressure tubes, in-situ inspections and research programs. Recommendations for further work are provided in the report.

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EXECUTIVE SUMMARY

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There is a 95% probability that, by 1990, pressure tube uniform oxide thicknesses will not exceed 31 microns in Pickering 3 and 4 and 45 microns in Bruce 2, in the region of the pressure tube where contact with the calandria tube is most likely to occur. There is also a 95% probability that, by 1990, assuming initial hydrogen levels of 10 ppm, equivalent hydrogen levels in Pickering 3 and 4 and Bruce 2 pressure tubes will not exceed 19 and 21 ppm in the inlet region (<275°C) and outlet region (>275°C), respectively. Oxides may however be thicker and equivalent hydrogen levels higher, in the lower flux high temperature region at the pressure tube outlet, as suggested by recent results from examination of pressure tubes F13 from Pickering 3 and K10 from Pickering 4.

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Pressure tubes have not been removed and hence data is not available from Pickering 5 and Bruce 3, the lead units for which Spacer Location and Repositioning (SLAR) is planned in the period 1987-1989. However, it is assumed that the oxidation behaviour of pressure tubes in these units is similar to pressure tubes in Pickering 3 and 4 and Bruce 2. Thus, for the body of pressure tubes in Pickering 5, by January 1990, predicted maximum uniform oxide thickness and equivalent hydrogen levels are 14 microns and 14 ppm respectively. Predictions for Bruce 3 pressure tubes are the same as those given above for Bruce 2, assuming effective full power hours are the same for both these units in 1990.

These predictions are based on limited data from examinations of a small number of pressure tubes relative to the total population. A major unknown in this work is the nature of the relationship between corrosion rate and deuterium pickup, and time for Zr-2.5 wt% Nb in the CANDU environment. Further research is thus required to understand the fundamental processes which govern rates of oxidation and deuterium pickup in thick oxides (>15 microns). The influences of pressure tube material composition and processing history, and heat transport chemistry on oxidation and deuterium pickup are also poorly understood, and these are to be the subject of further experimental and modelling work at OHRD. It is anticipated that results of this work will allow for the development of improved inspection criteria. Also, in view of the preliminary evidence that oxidation rate may be accelerating in the high temperature region of pressure tubes P3-F13 and P4-K10, some consideration should be given to developing practical in-situ techniques to reduce the rate of oxidation and deuterium pickup in Zr-2.5 wt% Nb pressure tubes.

On the basis of early and limited data, two pressure tubes at Bruce 2 (X14 and J11) show significantly higher average oxidation rates than those found on pressure tubes removed from Pickering 3 and 4. These high observed oxidation rates may be due to differences in pressure tube material. Oxidation rates observed in the body of Zr-2.5 wt% Nb pressure tubes showed Arrhenius-type behaviour. No obvious relationship was found between oxidation rate and fast neutron flux (E > 1.0 MeV). Considerable scatter was found in the amounts of deuterium picked up by pressure tubes compared to the total amount of deuterium produced by the oxidation process. Pressure tube G05 from NPD showed the highest value of deuterium pickup of 6.9% followed by pressure tubes from Pickering 3 and 4 (4.7%) and Bruce 2 (3.3%). No systematic trend between deuterium pickup and temperature, distance from the pressure tube inlet, or flux was found.

The methodology developed will be used to improve the corrosion model and confidence in predictions, as more data become available from removed pressure tubes, in-situ inspections, and research programs. In view of the high oxidation rates found for Bruce 2 pressure tubes X14 and J11, and the large scatter in the Bruce 2 data, further inspections and/or removals and examinations of pressure tubes are recommended for this unit, in addition to those presently planned for lead units at Pickering.

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MODELLING CORROSION AND DEUTERIUM PICKUP IN OPERATING REACTOR PRESSURE TUBES

1.0 INTRODUCTION

In August 1983, pressure tube G16 from Pickering 2, failed due to the propagation of a crack emanating from 'blisters' of solid hydride on the pressure tube outside surface. These blisters had formed as a result of migration of deuterium and hydrogen to cold spots produced at the location of contact between the hot pressure tube and the relatively cold calandria tube. Recent modelling of hydride blister growth has shown that, under ideal conditions, the size (depth and volume) of a blister is a function of the total bulk level of deuterium and hydrogen, and the total time that the pressure tube has been in contact with the calandria tube/1/. Since the concentration of hydrogen can be assumed to remain constant throughout the pressure tube life, increases in pressure tube equivalent hydrogen arising from absorption of deuterium during operation is the major factor to be considered in predicting pressure tube response after contact (TRAC).

The prime objective of the work, therefore, is to predict equivalent hydrogen levels in all Ontario Hydro operating reactor Zr-2.5 wt% Nb pressure tubes.

In order to prevent pressure tube - calandria tube contact from occurring in operating units, plans have been made to perform spacer (garter spring) location and repositioning (SLAR). It is presently planned that this procedure will be performed in Bruce 3 and 4 and Pickering 5 and 6, between 1987 and 1989/2/. In order to assist with the SLAR decision, therefore, predictions of equivalent hydrogen levels by 1990, have been made for pressure tubes in the lead units Pickering 5 and Bruce 3, in addition to those made for Bruce 2 and Pickering 3 and 4.

The zone of potential pressure tube-calandria tube contact is predicted to be in the central portion of the pressure tube between 160 cm and 152 cm from the

inlet and outlet respectively for Bruce 3 and 4, and between 152 cm from the inlet and 137 cm from the outlet for Pickering 5 and 6/3/. Thus, predictions of equivalent hydrogen levels in the central region of the pressure tube are of most value for SLAR.

Oxidation of the pressure tube inside surface during operation provides a major source of deuterium from the following reaction;

$$Zr + 2D_2O = ZrO_2 + 2D_2 \qquad (I)$$

Deuterium is also produced by radiolysis in the heat transport system and may be present in the annulus gas system. Also, deuterium is produced and absorbed by the pressure tube at the rolled joints, although deuterium entry by this route does not effectively contribute to bulk pressure tube deuterium levels at locations where calandria tube contact can occur. The relative contribution of each of these sources (other than the rolled joints) to pressure tube deuterium levels may vary. It has been generally recognized, however, that the corrosion reaction is the primary source of deuterium in the body of the pressure tube.

Thus, a secondary objective of this work is to predict oxidation on the internal surfaces of operating Zr-2.5 wt% Nb pressure tubes.

Unfortunately, there is a paucity of oxidation data for this material, particularly for long exposure times, which can be directly applied to CANDU pressure tubes. The most relevant data available to us has been obtained from ten pressure tubes removed from operating Ontario Hydro CANDU reactors. This represents a very small sample from the total population of operating Zr-2.5 wt% Nb pressure tubes. Also, only a small number of locations were examined on most pressure tubes, particularly in the body of the pressure tube away from the rolled joint regions. Predictions made in this report are based on this limited data base. As further data becomes available from removed pressure tubes, it will be incorporated in further analysis, to increase confidence in our predictions.

Whilst analysis of data from Zr-2.5 wt% Nb has been the primary focus of the present study, some analysis, more limited in scope, has been performed on data from Zircaloy 2 pressure tubes. A large amount of oxidation data is available for this material in the open literature, primarily on account of its use as a fuel cladding material in Pressurized Water Reactors. Since all Ontario Hydro CANDU units which are currently operating contain Zr-2.5 wt% Nb pressure tubes, results of analysis of Zircaloy 2 data are presented for the purposes of comparison with results of analysis of Zr-2.5 wt% Nb.

A major part of the work involves the establishment and continual updating of a data base containing information on oxidation and deuterium/hydrogen pickup in zirconium alloys in general and removed pressure tubes in particular. Analysis of this data has contributed to our understanding of the relationships between oxidation and deuterium pickup and variables such as fast neutron flux and temperature, and allowed us to provide short-term

predictions. This work has also helped to focus research in the area of pressure tube oxidation, as well as assisting in the selection of pressure tubes for removal and examination.

This report provides comprehensive documentation of all work to date. A more condensed version is to be included in the proceedings of the recent Fuel Channel Technology Seminar, held in Oakville, Ontario, in November 1985.

The work is part of the Fuel Channel Research Program/4/, Work Program No 503, Box No 3.4.12. Support has been provided by Design and Development Division, Central Nuclear Services, and Research Division.

2.0 PROCEDURE

2.1 Data Base

A diagram of the overall work plan is shown in Figure 1. The data survey covered all available data on oxidation of zirconium alloys in similar environments to CANDU. The data base was established with data obtained from removed Ontario Hydro pressure tubes, available in Atomic Energy of Canada reports/5-15/.

A summary of pressure tubes from which data was obtained together with effective full power hours and number of data points for oxide thickness and deuterium level, is shown in Table 1. With reference to this table, it can be seen that more data exists for Zircaloy 2 pressure tubes compared with Zr-2.5 wt% Nb. Analysis was performed at a number of axial locations on each pressure tube. Figure 2 schematically depicts the analysis conducted at each of the 45 axial locations for which measurements were taken. All numerically tabulated data were input to the data base.

Values of operating flux and temperature for each analysis location were also input to the data base. Fluences were provided based on calculations with the Fast Flux (FASF) or Simulation of Reactor Operation (SORO) Codes for each pressure tube for which data were available/16,17/. These were then converted to average flux by the relationship:

$$\text{Flux} = \text{Fast neutron fluence/EFPH}*3600 \qquad \text{(II)}$$

Axial temperature profiles were provided for Pickering A (based on 5 MW power output for all channels) and Bruce A (based on 5 MW and 6 MW for inner and outer zones) pressure tubes assuming a flow rate of 25 kg/s/18,19/. Differences were found between temperature profiles based on theoretical design calculations and those based on actual measurements of outlet temperatures of selected channels from operating reactors, which were chosen for this report. Temperature differences are also present between different clock positions at the same axial location in a pressure tube/20/. The 6 o'clock position is predicted to be hotter than the 12 o'clock position, with the temperature difference between these two positions increasing with operating time, as the amount of pressure tube diametral creep increases. In view of the lack of operating measurements to confirm this and the absence of

trends towards higher corrosion rate at the 6 o'clock position for Zr-2.5 wt% Nb, it was assumed for this analysis that a unique temperature exists at each axial location.

2.2 Data Analysis - Oxidation

As shown in Figure 1, two approaches were taken for data analysis. The first approach was to develop functional relationships between oxidation rate, flux and temperature. The effects of flux and temperature were found by separating data analysis into distinct flux and temperature regions. The oxidation rate (R), in its simplest form is determined by the expression;

$$R = (MOX - \text{average initial PT oxide thickness})/EFPH \qquad (III)$$

where MOX is the maximum uniform oxide thickness, and average initial pressure tube oxide thickness is 1 micron for both Zircaloy 2 and Zr-2.5 wt% Nb. R was chosen in order to normalize MOX with respect to effective full power hours (EFPH) for comparative purposes. Thus, a linear oxidation rate is assumed for the entire pressure tube operational life.

It is assumed that the maximum uniform oxide thickness represents a conservative estimate of total oxidation occurring during pressure tube in service life at any given location. Large differences were reported between the maximum and minimum uniform oxide thickness. These probably arose as a result of oxide removal (spalling) during the pressure tube removal and cutting operations. It is judged to be unlikely that significant spalling had occurred during the growth of oxide in-reactor/21/.

Since oxidation is a thermally activated process, it is assumed that the temperature dependence of oxidation rate (R) can be expressed by an Arrhenius-like exponential law, ie

$$R = A*\exp(-B/T) \qquad (IV)$$

where A and B are constants.

It is recognized that this Arrhenius relationship may be complicated by the unknown effect of flux on irradiation damage and oxidation processes in Zr-2.5 wt% Nb. From this assumption of an exponential law, however, LnR and 1/T have a linear relationship over the range of temperature under consideration. Therefore, values of the constants A and B may be obtained from slopes and intercepts of regression fits of the data.

The second approach for data analysis was to consider maximum uniform oxide thickness as a function of effective full power hours, and to fit the data to a regression model. This method was limited by the lack of time dependent data available to us. Predictions were made by extrapolating beyond the present data base, using both linear and quadratic relationships between maximum uniform oxide thickness and effective full power hours. Data from pressure tubes removed from Pickering 3 and 4 in 1975 (P3-J16/V09 and P4-R06) have only been included in this time dependent analysis, since data analysis

for these pressure tubes was limited (analysis was not performed at different clock positions) compared to other pressure tubes examined more recently.

These predictions are accompanied by an upper 95% confidence limit, U, calculated by the formula;

$$U = Y + 1.96\sigma \sqrt{[1 + 1/n + (X-\bar{x})^2/\Sigma_{i-1}^{n}(x_i-\bar{x})^2]} \qquad (V)$$

where Y is the prediction at a given value of the independent variable X, σ is the root mean square of the regression residuals, n is the sample size and $\bar{x}$ is the average of the observations x_i (i = 1,2, ..., n)

This methodology was developed as a means of obtaining preliminary predictions, hence providing the framework for the refinement of predictions when further data become available.

A partial analysis was only performed on Zircaloy 2 data, since predictions for this material were not required.

2.3 Data Analysis - Deuterium Pickup

Two methods for predicting pressure tube deuterium concentrations were used. Firstly, the ratio of actual deuterium pickup to maximum theoretical pickup of deuterium produced by the oxidation process (called % theoretical pickup) was determined. If 100% of the deuterium liberated by the oxidation reaction is absorbed by the pressure tube, this would be equivalent to a pickup of 14 ppm/micron for a pressure tube of 4 mm wall thickness. Using predicted oxide thicknesses, deuterium levels may be predicted assuming that the % pickup remains constant over the time of predictions.

The alternative method was to consider deuterium as a function of effective full power hours, and determine this function by fitting the data to a regression model.

3.0 RESULTS

3.1 Zr-2.5 wt% Nb

The data base for Zr-2.5 wt% Nb is shown in Appendix 1.

3.1.1 Oxidation

The distribution of flux versus temperature for all pressure tube axial locations from which measurements of oxide thickness were taken is shown in Figure 3. A reasonably flat flux profile is shown for Pickering 3 and 4 pressure tubes between approximately 252-292°C. Points for Bruce 2 pressure tubes J11 and X14 (BJX) are not uniformly distributed as a result of their being in different reactor zones with higher temperature at the inlet of X14 compared to J11. All data points for NPD lie below flux = 1.1×10^{13} n/cm^2*sec.

It should be noted that in Figure 3, and in other Figures that follow, a number of similar data points have been superimposed, and may appear as one point. This can result in incorrect visual interpretation of the data. Also, as stated above, data points for P3-J16, V09, and P4-R06 pressure tubes which were removed in the early life of Pickering 3 and 4, have not been included in this figure and a number of subsequent plots on account of the limited analyses performed on these pressure tubes. They have, however, been included where possible in analysis of data presented later.

Data analysis was done primarily for the high flux region above 1.5×10^{13} $n/cm^2 * sec$, in order to determine the T dependence in this region of relatively constant flux. Also two temperature ranges above and below 275°C were chosen, where 275°C represents approximately the median temperature.

Maximum uniform oxide thickness is plotted versus temperature in Figures 4a and b by pressure tube and by high and low flux respectively. Data for all clock positions and all axial locations are shown. In these figures, a trend is visible towards increasing oxide thickness with temperature, although these points represent pressure tubes with different operating times.

Micrographs showing cross-sections through the oxide-metal interface at locations marked in Figure 4a are shown in Figure 5. These show that large differences in uniform oxide thickness exist at the same axial location (but different clock positions) in a given pressure tube. For example P3-J09 shows uniform oxide thicknesses of 30 microns and 16 microns at the location 1 cm from the inlet (see Figures 5a and b). With reference to Figure 4, however, the oxide thickness of 30 microns appears to be spurious relative to the rest of the data. The oxide observed in the high temperature region (293°C) of P3-J09 is shown in Figure 5c. In view of the relatively thick oxides found in pressure tubes removed from Bruce 2 (relative to the operating time), a sample from B2-J11 is included in Figure 5d. Thick oxides found in the outlet region of P3-F13 are shown in Figures 5e and f, whilst a representative section of relatively thin oxide found close to the outlet of NPD-G05 are shown in Figure 5g. These micrographs reveal considerable differences in gross oxide morphology between different pressure tubes and within the same tube.

In Figures 6a and b, oxidation rate (R) is plotted versus temperature by pressure tube and by high and low flux respectively. In Figure 6a, a trend towards increasing oxidation rate with temperature can be seen, with higher values for B2-J11 and X14. Two data points attributed to P3-J09 at 250°C deviate from this trend. Values of oxidation rate for NPD-G05 (NG5) are generally low and do not reveal any obvious temperature dependence. With reference to Figure 6b, the majority of high flux data points lie between 255-294°C, with few low flux data points attributable mainly to NPD in this same temperature range.

Arrhenius plots of LnR versus 1000/T are shown for all pressure tubes both by pressure tube and by flux in Figure 7a and b. As in the previous figures, oxidation rate is seen to increase with increasing temperature in the body of the pressure tubes, with a large scatter at the pressure tube ends where low flux is present at high and low temperature.

In view of the differences in oxidation rate in pressure tubes from Bruce 2 and Pickering 3 and 4, data from these units were analyzed separately. Figure 8a shows the line of best fit for all data from Pickering 3 and 4 pressure tubes. Due to the large amount of scatter in data at the ends of the pressure tubes, linear regression was applied separately to the high flux data as shown in Figure 8b. For pressure tubes from Bruce 2, due to the lack of data over the temperature range, a regression fit was applied to all data as shown in Figure 8c (where data points are separated by pressure tube), and 8d (where data points are separated by high and low flux).

Values of slope, intercept, the squared multiple coefficient of correlation (R^2), and standard deviation (σ) determined from these figures are shown in Table 2. Also shown in this table are calculated values of oxidation rates at 250°C, 275°C, and 300°C.

Oxidation rates for pressure tubes from Bruce 2 are considerably higher than those from Pickering 3 and 4, although the apparent temperature dependence of the oxidation rate is lower in the case of Bruce 2. This could result from a high, but decreasing oxidation rate during the early period of operation rather than real overall differences in oxidation rate (see Section 4.2). Also, R^2 is extremely low in the case of data from Bruce 2 pressure tubes, indicating the need for more data to improve confidence in these results. For data from Pickering 3 and 4 pressure tubes, there is a higher R^2 value in the high flux region, than when all data is included, reflecting the scatter of data at the pressure tube ends.

In Figures 9a and b, oxidation rate is plotted versus flux both by pressure tube, and by high and low temperature respectively. No obvious trend of oxidation rate with flux is visible in these plots. As a result, further more detailed analysis was not done to determine the effects of flux.

All data for maximum uniform oxide thickness is plotted versus effective full power hours, by pressure tube, and high and low temperature, in Figures 10a and b respectively. In Figure 10a oxide thickness can be seen to increase with full power hours, despite the large scatter in oxide thickness data for P3-J09 and F13, and P4-N16, principally on account of the temperature dependence of oxidation rate. Oxide thicknesses for NPD-G05 (NG5) are low relative to the overall trend. Also B2-J11 and X14 show relatively high values after only 35 707 and 31 158 effective full power hours respectively. Data from B2-P12 does not, however, appear to support the high values of oxidation rate for pressure tubes from Bruce 2 compared to those from Pickering 3 and 4. In Figure 10b, oxide thickness is generally higher in the high temperature region, as was evident from earlier plots.

In view of the large amount of scatter of oxide thickness data in the low flux region (see Figure 4b), predictions were made only with data from the high flux region ($>1.5 \times 10^{13}$ n/cm^2*sec). Also, by choosing this flux region, data from NPD-G05, which show lower values of oxidation rate when compared to the other units, is eliminated.

In Figures 11a and b, regression fits are applied to the high flux oxide thickness data for the low and high temperature regions, assuming linear and

quadratic relationships between oxide thickness and operating time. These are forced through 1 micron which represents the initial oxide thickness following autoclaving. In view of the high values of oxide thickness for B2-J11 and X14 referred to earlier, it is not possible (using this approach) to make predictions for Bruce 2 based on the small amount of data for this unit. Thus predictions apply to pressure tubes from Pickering 3 and 4 only.

Values of slope, intercept and standard deviation, with predictions of maximum uniform oxide thickness for Pickering 3 and 4 for January 1990 (EFPH = 122 600), are shown in Table 3. Assuming a linear relationship between uniform oxide thickness and operating time until 1990, maximum uniform oxide thickness of 12 microns and 17 microns in the low and high temperature regions, respectively, are predicted. It is also predicted that there is a 95% probability uniform oxide thicknesses will not exceed 19 microns and 24 microns for the low and high temperature regions by the same time. These predictions are similar to those based on linear regression fitting of LnR vs 1/T shown in Table 2.

Assuming increasing oxidation rate with operating time, however, as given by a quadratic relationship, predictions increase to 17 and 24 microns for the low and high temperature regions, with values of 23 and 31 microns with a 95% confidence limit (see Table 3). Note that in this table, the squared multiple coefficients of correlation (R^2) are not given. Since the regression lines were forced through 1 micron, R^2 is not an appropriate measure of fit/22/.

Figures 11c and d show similar linear and quadratic fits applied to all data for oxide thickness versus operating time in the high temperature and low temperature regimes, including both high and low flux. Results in Table 3 show higher predicted oxidation rates when all data is accounted for. However, this includes data in regions of the pressure tube ends where contact with the calandria tube is not expected to occur.

Predictions for Pickering 5 have also been made as shown in Table 3, assuming that pressure tubes from this unit will show a similar trend of oxide thickness versus operating time to that observed for Pickering 3 and 4. Effective full power hours for Pickering 5 pressure tubes by January 1, 1990 are assumed to be 49 000 based on an average capacity factor of 80%.

3.1.2 Deuterium

Deuterium concentration is plotted versus distance in Figure 12a. High values at the pressure tube ends arise from deuterium ingress from the rolled joints. In Figure 12b all data from within 40 cm of the rolled joints are excluded in a plot of deuterium concentration versus distance. High values of deuterium concentration in P3-F13 and P4-N16 at distances of 582.6 cm and 585 cm from the pressure tube inlets are evident (see Figure 12b and Appendix 1). Also included is very recent data from P4-K10 (not given in Appendix 1) showing deuterium levels of 26-29 ppm at a distance of 583 cm from the inlet. The contribution of deuterium from the end fittings is negligible in this region. Thus, the high levels of deuterium found at between 582-585 cm from the inlet ends of these three pressure tubes would appear to indicate that rates of deuterium ingress are increasing in this high temperature region. Since it is

not expected that contact with the calandria tube will occur within 137 cm of the outlet (see Section 1.0), these high values have not been included in subsequent analysis for the purpose of developing predictions.

Percentage theoretical deuterium pickup is plotted versus distance and temperature in Figures 13a and b. As in the previous figures, no trend is evident, although a large amount of scatter in values of % theoretical deuterium pickup is present. Values for mean and standard deviation for deuterium pickup for each pressure tube, and unit(s) are shown in Table 4. Overall, % deuterium pickup is highest for pressure tubes at NPD (6.9%), followed by Pickering 3 and 4 (4.7%) and Bruce 2 (3.3%). Since the contributions of pressure tube deuterium from sources other than the corrosion reaction, to total pressure tube deuterium concentration is unknown, a high value of % deuterium pickup does not necessarily imply a high pickup of deuterium liberated by the corrosion reaction. However, by assuming % deuterium pickup remains constant until 1990, with reference to predicted oxidation rates and oxide thicknesses shown in Tables 2 and 3, it is possible to predict bulk pressure tube deuterium levels in 1990. These are given in Table 5 (columns B & C) as both predicted deuterium concentrations and equivalent hydrogen levels assuming an initial hydrogen concentration of 10 ppm.

Table 5 is intended to provide a summary of all predictions, generated by each method described in this report. In the far left hand column, the various methods are described. For Pickering 3, 4 and 5, linear regression and quadratic fits were applied to oxide thicknesses and deuterium concentrations versus time. Also as shown in Table 5, linear regression was applied to plots of LnR versus 1/T in order to determine oxidation rates at 275°C and 300°C. Column A shows values of calculated rate constants (in rows 1) and oxide thicknesses (in rows 2). Column B shows rate constants for deuterium pickup/effective full power hours (in rows 1) and deuterium concentration (in rows 2) determined using pickup factors (see Table 4) with oxide thicknesses in Column A. In Column C, equivalent hydrogen levels are shown where equivalent hydrogen = (0.5 x deuterium concentration) + 10 ppm. Where two figures are shown in each box separated by a /, these refer to predictions for two separate units (eg. Pickering 3, 4 and Pickering 5).

Figure 14a shows deuterium concentration versus effective full power hours by pressure tube. Only data at >40 cm from the pressure tube ends is included; this also has the same effect as excluding data from the high and low temperature regions. Similar trends to those shown in Figure 10a are revealed here, with P4-N16, K10 and P3-F13 showing particularly high levels of deuterium.

In Figures 14b and c, regression fits are applied to the data for deuterium concentration both for the low and high temperature regions, assuming both linear and quadratic relationships between deuterium concentration and operating time. Here data within 50 cm of the pressure tube ends has been excluded since predictions are required for the central region of the pressure tubes only. These are forced through a deuterium concentration of zero ppm. Consequently, the squared multiple coefficient of correlation was not

determined (see Section 3.1.1)/22/. Values of slope, and standard deviation with predictions of deuterium concentration for pressure tubes from Pickering 3 and 4 and Pickering 5 for January 1990, are shown in Table 6, and column B of Table 5. Assuming a linear relationship between deuterium concentration and operating time until 1990, for Pickering 3 and 4 pressure tubes, deuterium concentrations of 7 ppm and 8 ppm (3 ppm for Pickering 5) in the low and high temperature regions respectively are predicted. There is also a 95% probability that deuterium concentration will not exceed 10 ppm and 13 ppm (6 ppm and 8 ppm for Pickering 5) for the low and high temperature regions by the same time. Predictions for Pickering 5 assume 49 000 effective full power hours by January 1990, and similar behaviour to pressure tubes in Pickering 3 and 4.

Assuming an increasing rate of deuterium uptake with operating time, however, as given by a quadratic relationship, predictions for Pickering 3 and 4 pressure tubes increase to 9 ppm and 11 ppm for the low and high temperature regions (2 ppm for Pickering 5), with values of 13 ppm and 17 ppm with a 95% confidence limit (5 ppm and 7 ppm for Pickering 5) see Table 5.

As stated previously, maximum values of uniform oxide thickness and deuterium concentration predicted by all methods are compared in Table 5.

3.2 Zircaloy 2

The data base for Zircaloy 2 is shown in Appendix 2.

3.2.1 Oxidation

Plots of maximum uniform oxide thickness and oxidation rate as a function of temperature and flux have been generated for Zircaloy 2 pressure tubes, as they were for Zr-2.5 wt% Nb, although they have not been included in this report. Plots of LnR versus 1000/T are included, however, since they may be used to compare the behaviour of Zr-2.5 wt% Nb pressure tubes with those of Zircaloy 2, and they provide some insights into the validity of the analysis procedure. Since predictions for Zircaloy 2 are not required, plots of oxide thickness versus operating time have not been produced.

A plot of flux versus temperature for all axial locations of measurements is shown in Appendix 3, Figure 1. Plots of LnR versus 1000/T are shown in Appendix 3, Figures 2a and b for data from Pickering 1 pressure tubes from the 6 and 12 o'clock positions respectively. Linear regression fits shown apply to data from the high flux region only. These are compared in Appendix 3, Figure 2c. Similar plots are shown for data from pressure tubes from Pickering 2 in Appendix 3, Figures 3a, b and c. Values for slope, intercept, the squared multiple coefficient of correlation and standard deviation and calculated corrosion rates are shown in Appendix 3, Table 1.

These results show apparent differences in the temperature dependence of oxidation rate between the 6 and 12 o'clock positions. Corrosion rates at the 6 o'clock position show an apparently larger temperature dependence (higher slopes) than those at the 12 o'clock position. In the low temperature region, however, corrosion rates are approximately the same for both clock positions.

The observed differences in rates for the two clock positions is most likely a consequence of the predicted higher temperature at the 6 o'clock position referred to earlier (see section 2.1.) This apparent increased temperature dependence may be due to the earlier onset of 'breakaway' oxidation (transition to positive curvature kinetics) at high temperature in the case of Zircaloy 2. This will be discussed further in Section 4.2.

Oxidation rates for Zircaloy 2 pressure tubes shown in Appendix 3, Table 1 are significantly higher than those for Zr-2.5 wt% Nb given in Table 2, only in the high temperature regions. Oxidation rates for both materials are similar in the low temperature region close to the pressure tube inlet. Thus, it is the apparently higher temperature dependence of corrosion in the region of constant high flux in Zircaloy 2 pressure tubes compared to those of Zr-2.5 wt% Nb, that leads in part to the development of thicker oxides at the pressure tube outlet in the case of Zircaloy 2. The role of flux in the case of Zircaloy 2 has been shown to be equally, if not more important than that of temperature, as indicated by the decrease in oxide thickness in high temperature low flux regions close to the pressure tube outlet.

3.2.2 Deuterium

Percentage maximum theoretical deuterium pickup is plotted versus distance in Appendix 3, Figures 4a and b, for Pickering 1 and Pickering 2 pressure tubes respectively. As in the case of Zr-2.5 wt% Nb pressure tubes, no trend is evident from these figures. Mean values of % theoretical deuterium pickup for each pressure tube and Pickering 1 and Pickering 2 are shown in Appendix 3, Table 2.

4.0 DISCUSSION

4.1 Predictions

Highest predicted values (average and 95% confidence limit) of oxide thickness and equivalent hydrogen levels for all units taken from Table 5, are shown in Table 7. These predictions apply only to the central region of the pressure tubes where contact with the calandria tube is predicted.

By January, 1990, average maximum uniform oxide thicknesses (equivalent hydrogen levels) of 24, 7 and 19 microns (18, 12 and 15 ppm) are predicted in the high temperature region (>275°C) of pressure tubes in Pickering 3 and 4, Pickering 5, and Bruce 2 and 3 respectively. In the low temperature region, average predicted uniform oxide thicknesses (equivalent hydrogen levels) are 17, 6 and 18 microns (16, 11 and 14 ppm) for the same units.

There is a 95% probability that, by January 1990, maximum uniform oxide thickness (equivalent hydrogen levels) in the body of pressure tubes in Pickering 3 and 4, Pickering 5 and Bruce 3 and 4, will not exceed 31, 14 and 45 microns (20, 15, 21 ppm) respectively in the high temperature region (above 275°C). In the low temperature region, uniform oxide thicknesses (equivalent hydrogen levels) should not exceed 23, 12 and 40 microns (18,14, 20 ppm) for the same units.

Predictions for Pickering 5 and Bruce 3 have been developed on the assumption that oxidation and deuterium pickup rates in these units are similar to those in Pickering 3 and 4 and Bruce 2 respectively. Rates of oxidation and deuterium pickup have been found to vary widely between individual pressure tubes and units, and these variations remain unexplained. Hence extrapolations of results from units for which data is available to those for which there is no data is a questionable procedure, although the only one presently open to us. Thus, 95% confidence limits developed for Bruce 2 and Pickering 3 and 4 cannot be claimed for predictions for these other units.

These predictions are valid for the body of the pressure tubes in the high flux region where it is predicted that contact with the calandria tube can occur. Uniform oxide thicknesses may be higher at the pressure tube outlet near the rolled joints, although these regions are not of concern for SLAR since they are out of the region of predicted contact with the calandria tube. Also, equivalent hydrogen levels will be higher in the proximity of the rolled joints as a result of ingress and diffusion from the rolled joints, and observed increased rates of oxidation and deuterium pickup in this region (eg, P4-N16, K10 and P3-F13).

Also shown in Table 7 is the mean and lower bound of the terminal solid solubility (TSS)/23/ at 250°C and 275°C. For the purposes of this calculation the temperature at the contact location is assumed to be the predicted operating temperature, with no allowance made for temperature drop at the point of contact. Thus, actual values of TSS will be lower at the contact point than given here. Mean values of TSS of 31 and 45 ppm have been calculated for the low and high temperature regions respectively, with lower bound values of 20 and 28 ppm. Thus (for the low temperature region), equivalent hydrogen levels predicted with a 95% confidence level for Pickering 3 and 4 (18 ppm) and Bruce 2 and 3 (20 ppm) are approximately equal to the calculated lower bound value of TSS (20 ppm). The relevance of the predicted levels of equivalent hydrogen relative to TSS is uncertain, although it is generally believed that hydrides will begin to precipitate once the level of equivalent hydrogen reaches TSS. Where contact with the calandria tube occurs, however, the resulting drop in temperature will both decrease the effective TSS at the contact region, and increase the level of equivalent hydrogen by endothermic migration of hydrogen and deuterium to the relatively cold spot on the pressure tube outside surface. Furthermore, locally high oxidation rates on pressure tube outside surfaces may occur (as a result of fretting) at the locations of contact with the calandria tube, resulting in high deuterium pickup at these contact points. Also, since initial hydrogen levels in some pressure tubes are significantly higher than 10 ppm (the level used for the present calculations), actual levels of equivalent hydrogen will be higher than those predicted above.

Values of flux and temperature input to the data base (see Appendices 1 and 2), are based on data from several sources as discussed in Section 2.1. Some uncertainty exists as to the precise values of these variables, and further work may be necessary to resolve these differences.

Axial profiles for both temperature and flux are assumed to be smooth, although it is generally accepted that local variations will exist along a

fuel bundle. Also these profiles represent the average values of flux and temperature over the operational pressure tube life; local variations as a result of fueling history, or long-term changes (both axially and circumferentially) as a result of pressure tube creep are not accounted for at this stage, although data is available to deduce the time dependence of temperature and flux. Due to the complexities involved in more accurate determination of these variables at a given measurement location, and the reasonable trends apparent in the present analysis, further more detailed analysis of local perturbations in these variables is not judged to be warranted at this time.

4.2 Oxidation

A limitation of this analysis arises from the assumption that for the central region of the pressure tube, oxidation rate is constant within the time frame analyzed, and remains constant until the end of predictions in 1990. However, in the case of extrapolations of time-dependent data, an increasing rate has been modelled using quadratic fits to the data. In view of the lack of data for Zr-2.5 wt% Nb in environments similar to CANDU, a relationship between oxidation rate and time is not available. However, based on experience with zirconium alloys in general, a suggested form of this relationship is shown in Figure 15/21/.

The observed thin oxides (1 micron) on pressure tubes following autoclaving suggest that transition to stage 1 linear kinetics has not been reached, and the initial stages of oxidation in-reactor will follow a parabolic rate law, with decreasing oxidation rate. This may partly explain the relatively high value of rates of oxidation found in pressure tubes from Bruce 2, although the different behaviour of B2-X14, J11 and B2-P12 shown in Figure 6a, suggest an alternative explanation related to differences in pressure tube material, is more plausible. Further analysis of pressure tubes from Bruce A is recommended to establish greater confidence in the data.

Since the time taken to reach the point at which positive curvature kinetics (see Figure 15) occur will decrease with increasing temperature, it will occur at the locations of highest temperature at the pressure tube outlet first. This may result in an apparently higher temperature dependence of oxidation rate on temperature in pressure tubes where this transition has occurred. In the case of Zircaloy 2, Figures 2 and 3 in Appendix 3 appear to indicate that this transition has occurred in the high temperature region. Application of linear regression to Arrhenius plots of LnR vs 1/T is strictly speaking invalid in this case although it offers a means of comparing data between Zircaloy 2 and Zr-2.5 wt% Nb.

There is no evidence from similar plots of Zr-2.5 wt % Nb (Figure 8), that such a transition has occurred. However, Figure 11c shows apparently higher values of uniform oxide thicknesses relative to the general trend for P3-F13. This has been interpreted to imply the possible onset of positive curvature kinetics in this pressure tube/24/. Although it represents a small amount of data relative to the total population, it is especially significant since P3-F13 is the longest-running pressure tube for which data are available from either Pickering or Bruce. Also, very recent analysis of P4-K10 would appear

to confirm these observations. There are presently insufficient data to judge whether similar transitions will occur at lower temperatures in the body of pressure tubes prior to the end of the period for which predictions are made, ie, 1990, although this is judged to be unlikely.

Changes in oxidation rate can best be found by monitoring oxide growth in operating pressure tubes using in-situ inspection techniques with high resolution. Rate changes may also be predicted by the development of a physical model based on improved fundamental understanding of corrosion processes gained through a program of experimental work.

A further major assumption in our modelling of the effect of temperature is that in-reactor oxidation rate increases with temperature following an Arrhenius type relationship similar to that observed out-reactor. Cox/25/ has proposed that for Zircaloy 2 corrosion in-reactor, this relationship is not valid over the temperature range of 200-440°C, and in the temperature range 250-300°C there is effectively a low temperature dependence. This hypothesis is relatively recent however, and there is insufficient data available for Zr-2.5 wt% Nb to establish a similar behaviour for this alloy. In fact, if flux effects on Zr-2.5 wt% Nb are low in this temperature range, this effective in-reactor temperature dependence should be close to that observed in the laboratory. Temperature would then be the major variable along a pressure tube, and this temperature dependence of the oxidation rate (within the operating temperature range) would lead to the development of relatively thick oxides appearing first close to the pressure tube outlet.

Variables such as pressure tube material and heat transport chemistry (eg, hydrogen and oxygen levels) have not been included in the present data base and hence have not been accounted for in this analysis. These will be incorporated in future work. It is recognized that pressure tube material composition and processing history will vary between pressure tubes and particularly between stations. There is evidence that these differences could result in significant differences in corrosion and deuterium uptake rates/26,27/. Also, environment, particularly critical parameters such as oxygen and hydrogen levels, vary between stations and hence may contribute to observed differences in oxidation and deuterium pickup rates between pressure tubes.

The effect of flux has been more difficult to model, since the flux profile is relatively flat along a large part of the pressure tubes (at least for Pickering 3 and 4 where the bulk of data is available), whereas the temperature distribution shows a continuous increase along the body of the pressure tube. In the plots of oxidation rate versus flux in Figures 9a and b, the low flux regions occur both at low and high temperature, where both high and low oxidation rates are expected based on temperature dependence. Since it is not possible to isolate a region of changing flux within a narrow temperature range, it is difficult to draw any firm conclusions regarding the effect of flux, although no visible relationship between oxidation rate and flux is evident from the present data.

In the case of Zircaloy 2 in-reactor oxidation, flux has been regarded as an additional contributor to the thermal process. Enhanced in-reactor corrosion,

when compared to autoclave data at comparable temperatures, has been accommodated in terms of an empirical multiplicative term C in equation IV (see section 2.2)/28/, ie;

$$R = A*\exp(-B/T)*C \qquad \text{(VI)}$$

Very recently however, the flux effect has been expressed as an additive term/25,29/, ie;

$$R = A*\exp(-B/T) + C \qquad \text{(VII)}$$

There is evidence that the short-term effect of flux is negligible or could result in suppression of corrosion in the case of quenched, cold-worked and aged Zr-2.5 wt% Nb/30/. This has been explained on the basis of flux contributing to the annealing process in two-phase Zr-2.5 wt% Nb material. There is insufficient data in the literature to ascertain whether this flux suppression effect is maintained after long exposure times when it is expected that the contribution of flux to the annealing process would be negligible. Thus, it is possible that after long in-reactor exposures, the presence of flux would result in higher oxidation rates.

4.3 Deuterium Pickup

A large variability in % theoretical deuterium pickup has been observed. Differences in deuterium pickup between pressure tubes in the same unit, and overall pickup rates in given units, suggests that it may be governed by a number of factors.

Recent reviews of the mechanism of hydrogen and deuterium absorption in Zirconium alloys/31,32/ suggest that environment, particularly hydrogen:oxygen ratio plays a key role. Also, recent analysis of the possible effect of impurity elements on deuterium pickup in Zr-2.5 wt% Nb pressure tubes/26/ has indicated a possible correlation between pickup and a parameter X where:

$$X = 0.5 \times \text{wt\%}\ (Fe + Cr) + 2 \times \text{wt\%}\ C + 3.95 \times \text{wt\%}\ Ni \qquad \text{(VIII)}$$

Since deuterium ingress arises from a number routes (see Section 1.0), future predictions of rate of deuterium ingress as a function of factors such as operating time, temperature, flux, material and environment will be difficult. Fundamental research is required to improve understanding of pickup processes and the influence of these variables. Further work is ongoing at Ontario Hydro Research Division to improve our understanding of the effect of impurity elements on oxidation and deuterium pickup referred to above.

For the purposes of developing practical predictions, assumptions that have been made concerning deuterium pickup are essentially the same as those discussed above relative to oxidation, namely that the overall rate of deuterium pickup remains constant until 1990. Thus, it is not possible to determine if the rate of deuterium pickup has changed over the pressure tube operational life.

5.0 SUMMARY AND CONCLUSIONS

5.1 Short-term predictions of maximum uniform oxide thicknesses on internal surfaces, and equivalent hydrogen levels in the body of Zr-2.5 wt% Nb pressure tubes in Pickering 3 and 4, and Bruce 2 have been made based on analysis of limited data from examinations of ten Zr-2.5 wt% Nb pressure tubes removed from these units. Predictions for Pickering 5 and Bruce 3 have been made on the assumption that pressure tube oxidation and deuterium pickup in these units is similar to that found in Pickering 3 and 4, and Bruce 2, respectively.

5.2 Predictions are limited by the small amount of data available. Further data from pressure tube in-situ inspections, examinations of removed Zr-2.5 wt% Nb pressure tubes, and experimental programs, would result in an improved model and hence increased confidence in predictions.

5.3 By January 1990, for Pickering 3 and 4, Pickering 5, and Bruce 2 and 3, average uniform oxide thicknesses of 24, 7 and 19 microns are predicted in the body of pressure tubes in the high temperature region close to the pressure tube outlet. Average equivalent hydrogen levels of 18, 12 and 15 ppm are predicted in the same location assuming an initial hydrogen level of 10 ppm.

5.4 There is a 95% probability (in the case of Pickering 3 and 4 and Bruce 2) that average oxide thickness will not exceed 31, 14 and 45 microns for Pickering 3 and 4, Pickering 5, and Bruce 2 and 3 respectively. There is also a 95% probability that equivalent hydrogen level will not exceed 20, 15 and 21 ppm.

5.5 These predictions are valid for the body of the pressure tubes only, where contact with the calandria tube is predicted. Local patches of oxide may exceed these predictions. The probability of equivalent hydrogen levels exceeding predictions is greatest in pressure tubes with high initial hydrogen levels (i.e. in excess of 10 ppm) and high levels of impurity elements (Ni, C, Fe, Cr).

5.6 It has been assumed that the oxidation rate and rate of deuterium uptake remain constant until the end of predictions. Rate increases similar to those found in Zircaloy 2 pressure tubes may occur in the body of Zr-2.5 wt% Nb pressure tubes before 1990, although presently it is not possible to predict the timing or magnitude of a change in rate.

5.7 Higher oxidation rates have been observed for Bruce 2 compared to Pickering 3 and 4. Further examinations and/or inspections of pressure tubes from this unit are needed to establish the reliability and interpretation of this observation.

5.8 Corrosion rates for Zr-2.5 wt% Nb pressure tubes were found to show Arrhenius-type behaviour in the high flux region above 1.5×10^{13} n/cm^2*sec. For Zircaloy 2 pressure tubes, there is some indication of departure from Arrhenius behaviour, probably on account of

the occurrence of transition to positive curvature kinetics occurring in this material in the high temperature regions.

5.9 Relatively high values of maximum uniform oxide thickness and deuterium levels have been observed for pressure tubes P4-N16, K10 and P3-F13, possibly indicating the beginning of a trend towards increased oxidation and deuterium uptake rates close to the outlets in Zr-2.5 wt% Nb pressure tubes. However, it is judged to be unlikely this will affect the above predictions in the body of Zr-2.5 wt% Nb pressure tubes relative to the timing of SLAR. Also, the transition to increasing oxidation rate (with associated increases in deuterium pickup), when and if it occurs at lower temperatures, would be expected on the basis of physical mechanistic solid state processes, to be gradual, taking several years to fully establish a new linear steady state rate.

5.10 No obvious relationship between flux and oxidation rate was found. A literature review suggests that in the case of Zr-2.5 wt% Nb, flux contributes to both material annealing (aging), which is known to decrease oxidation rate, and the enhancement of thermal processes which can result in rate increases.

5.11 Percentage theoretical deuterium pickup was found to vary greatly between individual pressure tubes in the same unit and different units, suggesting that no single factor governs rate of pickup. Average % deuterium pickup was highest for Zircaloy 2 pressure tubes - 57% for Pickering 1, and 28% for pressure tubes from Pickering 2. For Zr-2.5 wt% Nb pressure tubes, values of average % deuterium pickup of 6.9%, 4.7% and 3.3% were found for pressure tubes removed from NPD, Pickering 3 and 4 and Bruce 2 respectively.

5.12 Higher oxidation rates observed in Zircaloy 2 in the high temperature region compared to Zr-2.5 wt% Nb probably result from the transition to positive curvature kinetics occurring at shorter times for a given temperature (and flux) in the case of Zircaloy 2.

6.0 RECOMMENDATIONS AND FURTHER WORK

6.1 Additional pressure tube removals and examinations are required in order to increase the data base and hence improve confidence in predictions. In view of the high oxidation rates found in pressure tubes from Bruce 2, further pressure tube inspections are recommended for this unit, in addition to those presently planned for lead units at Pickering. Future planned work will assist in defining selection criteria for further pressure tube inspection/removal (see section 6.3). Further measurements of existing removed pressure tubes are not recommended, in view of their low operating times.

6.2 Procedures should be developed to process additional data from removed pressure tubes and in-situ inspections using the methodology outlined in this report. This should include early access to all data with associated temperature and flux profiles, and the setting up of computer programs at Research Division to process the data as it becomes

available. This would allow for a rapid assessment of the significance of additional data, and its impact on predictions.

6.3 Further modelling is required to understand the role of heat transport chemistry and pressure tube material on oxidation and deuterium pickup, and to develop further understanding of the effects of temperature and flux, by resolving reported differences in these variables, and possibly incorporating short-range (axial and circumferential) fluctuations in the analysis. Consideration is being given to multivariant/discriminant analysis to achieve this objective. This will assist in defining the selection criteria for pressure tube inspection/removal and may result in improved chemical control in operating units.

6.4 Incorporation of data from fuel examinations in further analysis is recommended, as a means of improving understanding of fuel corrosion, and possibly leading to the development of a tool to predict pressure tube oxidation based on the performance of fuel.

6.5 Future research should be directed towards an improved understanding of the processes of corrosion and deuterium uptake in Zr-2.5 wt% Nb. A principal focus should be to determine the relationship between the rate of oxidation and deuterium pickup and time for Zr-2.5 wt% Nb. Emphasis should be given to the study of this relationship in thick oxides (>15 microns). Work should also be undertaken to develop and evaluate in-situ remedial treatments for Zr-2.5 wt% Nb pressure tubes to alleviate the effects of 'breakaway' oxidation, as a possible alternative to retubing.

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TABLE 1

SUMMARY OF DATA FROM REMOVED PRESSURE TUBES

Unit	PT	Material	EFPH	# Locations for Analysis	
				Oxide Thickness	Deuterium
P1	G16	Zr 2	89,012	22	22
	G20			10	10
	K05			13	13
	K18			13	14
	G14			3	3
P2	G16	Zr 2	86,840	32	24
	J15			15	19
	K13			--	1
	V09			1	1
P3	J16	Zr-2.5 Nb	13,800	7	—
	V09			5	—
	J09		83,674	16	19
	F13		91,000	4	7
P4	R06	Zr-2.5 Nb	15,100	16	24
	N16		82,360	5	—
B2	X14	Zr-2.5 Nb	31,158	4	4
	J11		35,707	3	3
	P12		54,800	2	3
NPD	G07	Zr 2	102,000	7	7
	G05	Zr-2.5 Nb		8	8

TABLE 2

Zr-2.5 wt% Nb PRESSURE TUBE CORROSION RATES BETWEEN 250-300°C BASED ON LINEAR REGRESSION(1) OF LnR VS 1/T

Unit-PT			P3-F13,J09 and P4-N16		B2-J11,X14,P12
			All Flux	Flux $>1.5\times10^{13}$ n/cm^2*s	All Flux
Intercept (LnA)			12.05	11.18	6.34
Slope (B)			-5.34	-4.88	-1.81
Standard Deviation (σ) (LnR)			0.56	0.19	0.42
Correlation Coefficient (R^2)			31%	59%	5%
Oxidation Rate(R)(2) (microns/hr) ($\times10^5$)	250°C	Average	6.3	6.4	17.8
		95%	19.3	9.3	41.2
	275°C	Average	10.0	9.7	20.8
		95%	30.7	14.2	48.3
	300°C	Average	15.3	14.4	24.1
		95%	47.0	21.0	55.8

(1) Assuming Linear Relationship between Maximum Uniform Oxide Thickness (MOX) and effective full power hours (EFPH).

(2) Where $LnR = Ln\ A - B/(T \times 10^{-3})$

TABLE 3

PREDICTIONS OF PICKERING PRESSURE TUBE MAXIMUM UNIFORM OXIDE THICKNESS (MOX) BASED ON LINEAR AND QUADRATIC FITS OF MOX VS EFPH[1]

			High Flux[2] (>1.5x10^{13} n/cm^2*sec)				All Flux			
			Linear (R=a+bt)		Quadratic (R=a+bt^2)		Linear (R=a+bt)		Quadratic (R=a+bt^2)	
			High T >275°C	Low T <275°C	High T >275°C	Low T <275°C	High T >275°C	Low T <275°C	High T >275°C	Low T <275°C
Slope (b)			1.28x10^{-4}	9.08x10^{-5}	1.49x10^{-9}	1.03x10^{-9}	1.48x10^{-4}	9.19x10^{-5}	1.76x10^{-9}	1.06x10^{-9}
Intercept (a) (microns)			1	1	1	1	1	1	1	1
σ (Microns)			3.42	3.2	3.74	3.86	3.74	4.86	4.48	5.11
Predicted MOX (microns)	P3,4[3]	Average	17	12	24	17	19	12	27	17
		95%	24	19	31	23	28	23	36	27
	P5[4]	Average	7	5	5	4	7	5	5	4
		95%	14	12	11	10	16	14	16	14

(1) for Pressure Tubes
B2-J11,X14,P12
P3-F13,J09,J16,V09
P4-N16,R06

(2) Excludes P3-J16, V09
P4-R06

(3) Assuming EFPH = 122,600 by January 1990

(4) Assuming EFPH = 49,000 by January 1990.

Based on average capacity factor of 80%

TABLE 4

PERCENTAGE THEORETICAL DEUTERIUM PICKUP(1)
FOR Zr-2.5 wt% Nb PRESSURE TUBES

Unit	Pressure Tube #	% Theoretical Pickup	
		Mean	Standard Deviation (σ)
B2	J11	3.89	1.69
B2	X14	2.51	0.68
B2	P12	4.44	0.75
B2	J11,X14,P14	3.34	1.12
P3	F13	5.65	1.14
P3	J09	3.26	1.05
P4	N16	7.17	0.98
P3,4	F13,J09,N16	4.69	1.01
NPD	G05	6.89	1.33

(1) Where 100% Theoretical Deuterium Pickup = 14 ppm/micron oxide for a pressure tube (wall thickness ~4 mm)

TABLE 5

PREDICTIONS[a] OF CORROSION AND DEUTERIUM LEVELS IN THE BODY[b] OF Zr-2.5 wt% Nb PRESSURE TUBES BY 1990

METHOD		A: (1) Rate Constant μm/EFPH x 10^5 (2) Oxide Thickness (microns)				B: (1) Rate Constant ppm/EFPH ($x10^5$) (2) D Conc (ppm) (4.7% D pickup)				C: (1) TSS (Mean/Lower Bound) 275°C/250°C (2) Equivalent H[d]			
		Mean		95%		Mean		95%		Mean		95%	
	Pickering 3,4/5(c)	>275°C	<275°C	>275°C	<275°C	>275°C	<275°C	>275°C	<275°C	>275°C	<275°C	>275°C	<275°C
From MOX vs Time	Linear Regression (P3,4/P5) (1)	12.84	9.08	-	-	-	-	-	-	45 / 28	31 / 20	45 / 28	31 / 20
	(2)	17 / 7	12 / 5	24 / 14	17 / 12	11 / 4	7 / 3	15 / 9	11 / 7	16 / 12	14 / 11	18 / 15	16 / 14
	Quadratic Fit (P3,4/P5) (1)	$1.49x10^{-4}$	$1.03x10^{-4}$	-	-	-	-	-	-	-	-	-	-
	(2)	24 / 5	17 / 4	31 / 11	23 / 10	15 / 3	11 / 3	20 / 7	15 / 7	18 / 12	16 / 11	20 / 14	18 / 14
From LnR vs 1/T	Linear Regression (P3,4/P5) (275°C,300°C) (1)	12.72	9.73	18.59	14.22	-	-	-	-	-	-	-	-
	(2)	17 / 6	13 / 6	24 / 10	18 / 8	11 / 3	9 / 3	15 / 7	11 / 5	16 / 12	15 / 11	18 / 14	16 / 13
From Deuterium Concentration vs Time	Linear Regression (P3,4/P5) (1)	-	-	-	-	6.83	5.73	-	-	-	-	-	-
	(2)	-	-	-	-	8 / 3	7 / 3	13 / 8	10 / 6	14 / 12	14 / 11	17 / 14	15 / 13
	Quadratic Fit (P3,4/P5) (1)	-	-	-	-	$7.23x10^{-5}$	$6.07x10^{-5}$	-	-	-	-	-	-
	(2)	-	-	-	-	11 / 2	9 / 2	17 / 7	13 / 5	16 / 11	15 / 11	19 / 14	17 / 13
	Bruce 2,3(c)					(3.34% D pickup)							
From LnR vs 1/T	Linear Regression (275°C/300°C) All flux (1)	$23.02x10^{-5}$	$20.84x10^{-5}$	$52.27x10^{-5}$	$47.33x10^{-5}$	-	-	-	-	-	-	-	-
	(2)	19	18	45	40	9	8	21	19	15	14	21	20

(a) For P3,4 and P5
B2 and B3

(b) For locations where contact with calandria tube is predicted.

(c) EFPH to JAN 1990 — P3,4 = 122,600; P5 = 49,000; B2,3 = 84,129 — Estimate Based On 80% Capacity Factor

(d) For initial hydrogen levels of 10 ppm
Note: Where 2 numbers are included in the same box separated by / they refer to P3,4 and P5 respectively.

TABLE 6

PREDICTIONS OF PRESSURE TUBE DEUTERIUM CONCENTRATION IN PICKERING 3,4[1] BY 1990 BASED ON LINEAR AND QUADRATIC FITS OF DEUTERIUM CONCENTRATION VS EFFECTIVE FULL POWER HOURS[2] (EFPH)

	Linear ($R = a + bt$)		Quadratic ($R = a + bt^2$)	
	Hight T >275°C	Low T <275°C	High T >275°C	Low T <275°C
Slope (b)	6.83237×10^{-5}	5.73227×10^{-5}	7.22823×10^{-10}	6.06866×10^{-10}
Intercept (a)	0	0	0	0
σ	2.4	1.7	3.1	2.0
Predictions	8.4	7.0	10.9	9.1
95% Confidence Level	13.2	10.4	17.1	13.1

(1) Pickering 3,4 Effective Full Power Hours to Jan 1990 = 122,600

(2) For Pressure Tubes

B2 - J11,X14,P12
P3 - F13,J09
P4 - N16
NPD - G05

TABLE 7

PREDICTED OXIDE THICKNESS AND EQUIVALENT HYDROGEN LEVELS IN THE BODY(1) OF Zr-2.5 wt% Nb PRESSURE TUBES BY 1990

		Pickering 3,4		Pickering 5		Bruce 2,3	
EFPH (to Jan 1990)(2)		122,600		49,000		84,129	
Temperature Region		>275°C	<275°C	>275°C	<275°C	>275°C	<275°C
Max Uniform Oxide Thickness (Microns)	Average	24	17	7	6	19	18
	95%	31	23	14	12	45	40
Equivalent (3) Hydrogen (ppm)	Average	18	16	12	11	15	14
	95%	20	18	15	14	21	20
Terminal Solid Solubility (at 275°C & 250°C)	Mean	45	31				
	Lower bound	28	20				

(1) At locations where contact with calandria tube is predicted.
(2) Estimate based on 80% capacity factor.
(3) Assuming 10 ppm initial hydrogen level.

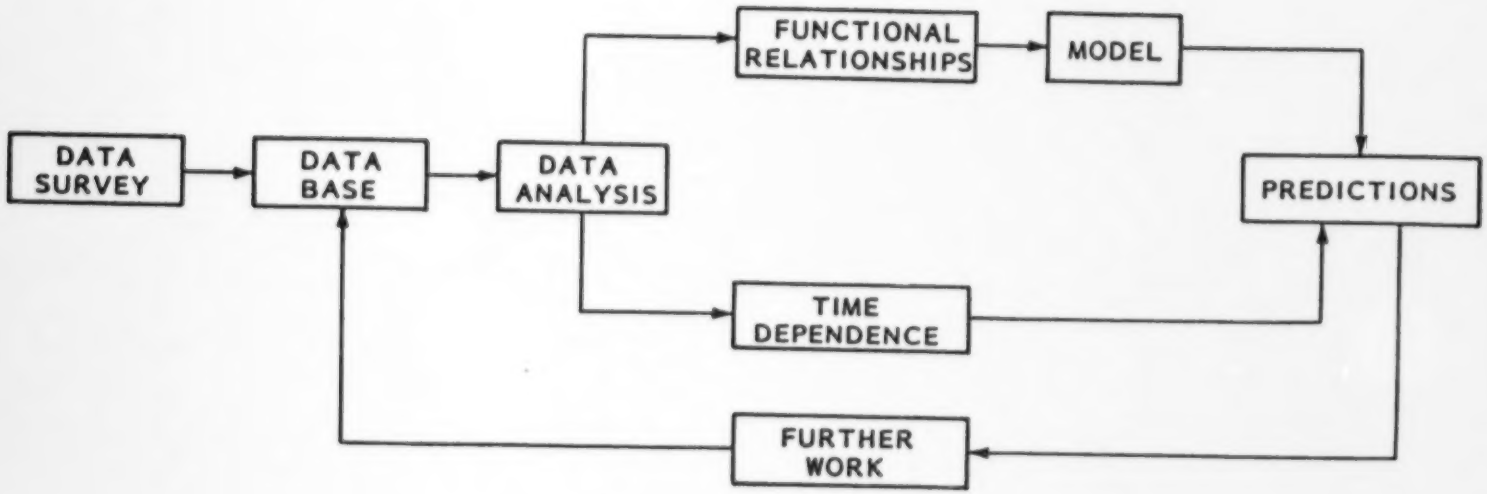

FIGURE 1: WORK PLAN FOR MODELLING OF CORROSION AND DEUTERIUM PICKUP IN PRESSURE TUBES

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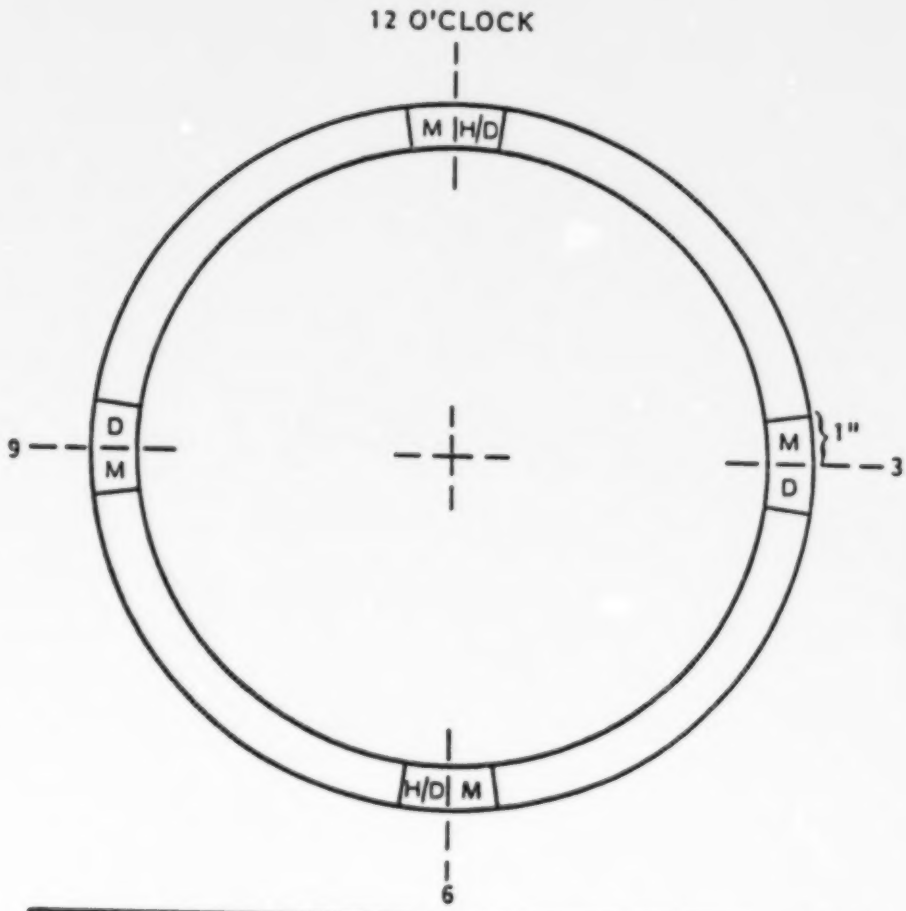

H = HYDROGEN ANALYSIS
D = DEUTERIUM ANALYSIS
M = METALLOGRAPHIC ANALYSIS (OXIDE THICKNESS)

OXIDE THICKNESS

- MAXIMUM (UNIFORM OXIDE)
- RANGE
- AVERAGE
- PATCHES
- SPALLING

H/D ANALYSIS

- RANGE
- AVERAGE

FIGURE 2: DIAGRAM OF LOCATIONS OF ANALYSIS PERFORMED ON EACH PRESSURE TUBE AXIAL LOCATION.

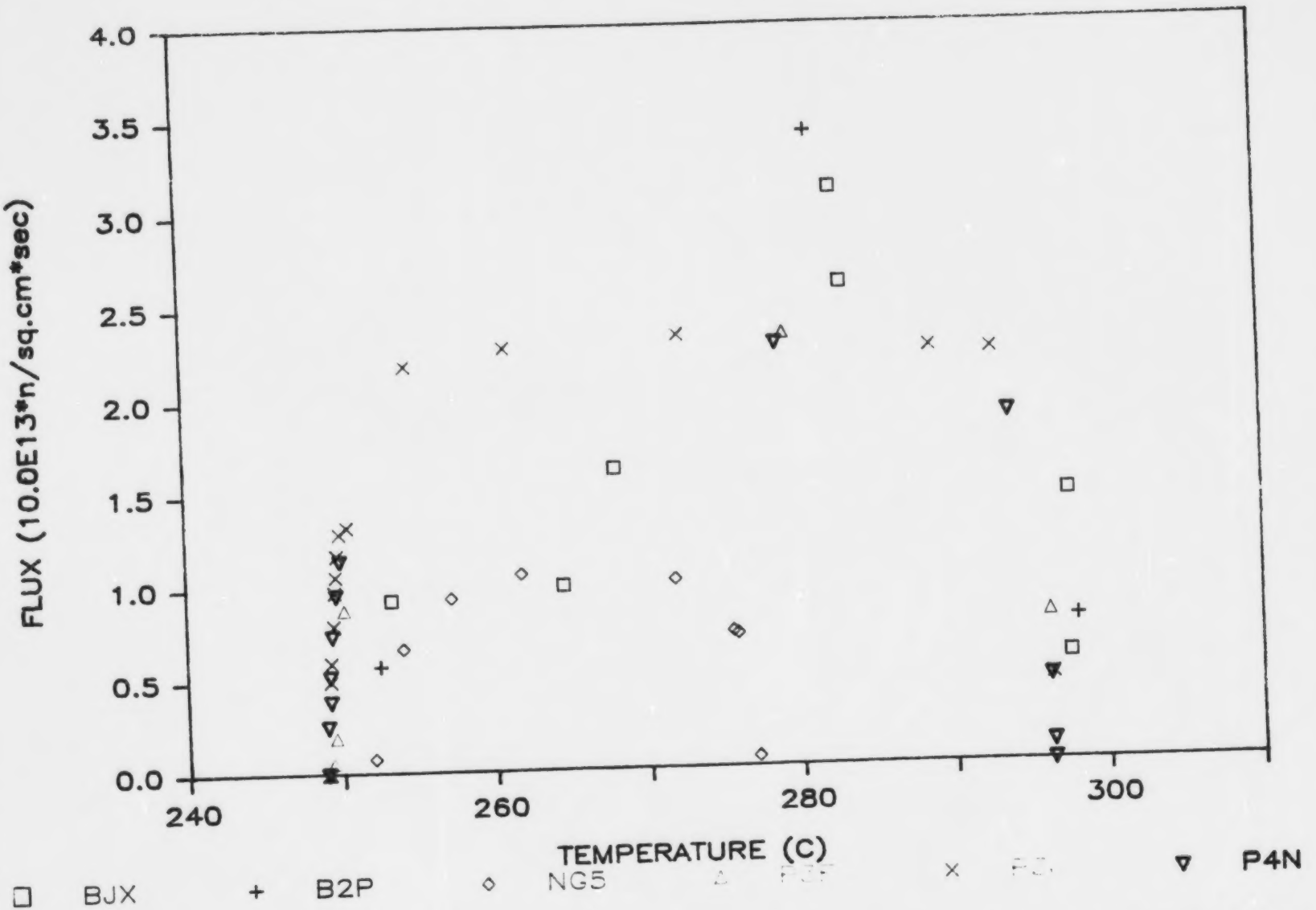

FIGURE 3: FLUX AND TEMPERATURES FOR ALL AXIAL LOCATIONS OF MEASUREMENTS FOR Zr-2.5 wt% Nb PRESSURE TUBES P3-F13, J09/P4-N16/B2-X14, J11, P12/NPD-G05

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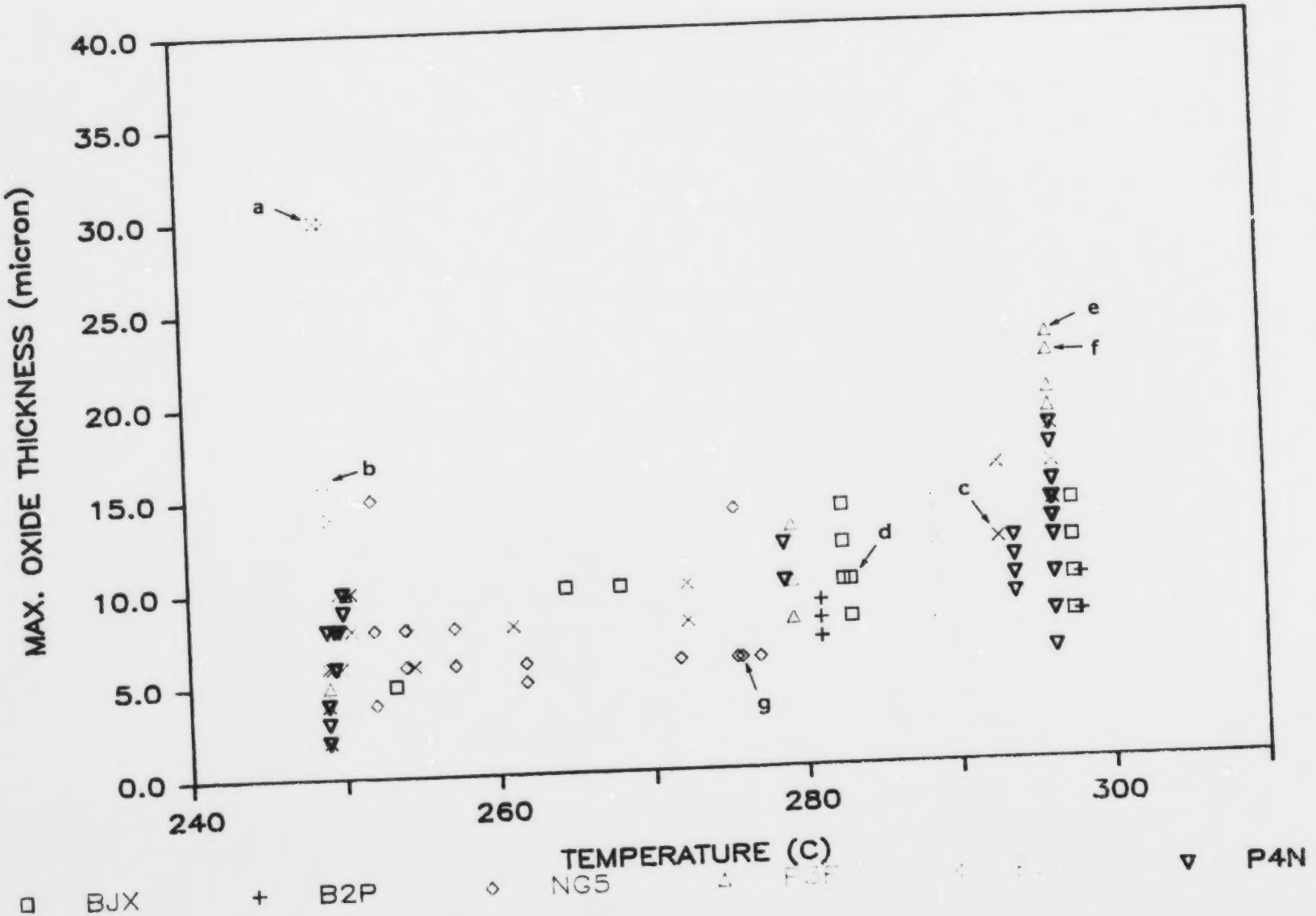

FIGURE 4a: MEASURED MAXIMUM UNIFORM OXIDE THICKNESS VS TEMPERATURE FOR Zr-2.5 wt% Nb PRESSURE TUBES P3-F13, J09/P4-N16/B2-X14, J11, P12/NPD-G05 (a-g - REPRESENT POINTS FOR OPTICAL MICROGRAPHS SHOWN IN FIGURE 5)

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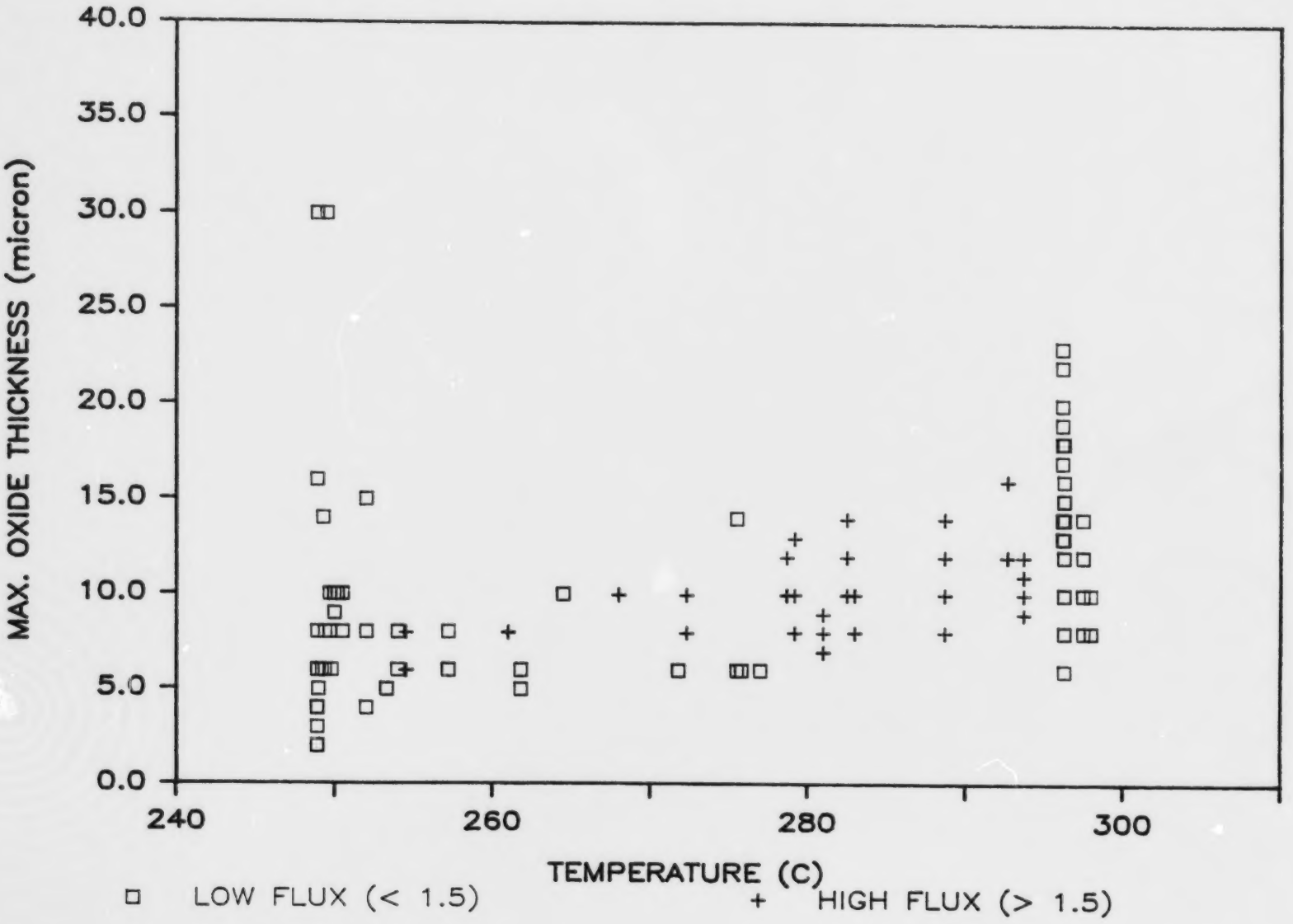

FIGURE 4b: MEASURED MAXIMUM UNIFORM OXIDE THICKNESS VS TEMPERATURE FOR Zr-2.5 wt% Nb PRESSURE TUBES P3-F13, J09/P4-N16/B2-X14, J11, P12/NPD-G05 BY HIGH FLUX ($>1.5X10^{13}$ n/cm^2*sec) AND LOW FLUX ($<1.5X10^{13}$ n/cm^2*sec)

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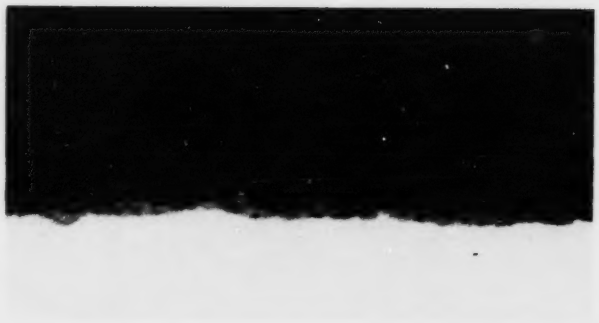
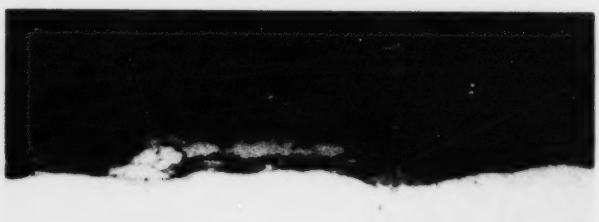


(a) P3-JO9, 1 cm FROM INLET, 6 O'CLOCK, 500X, MAX. OX. THICKNESS ~ 30 MICRONS

(b) P3-JO9, 1 cm FROM INLET, 12 O'CLOCK, 500X, MAX. OX. THICKNESS ~16 MICRONS

(c) P3-JO9, 493 cm FROM INLET, 6 O'CLOCK, 500X, MAX OX. THICKNESS ~12 MICRONS



(d) B2-J11, 340 cm FROM INLET, 12 O'CLOCK, 500X, MAX. OX. THICKNESS ~ 10 MICRONS

FIGURE 5: OPTICAL MICROGRAPHS SHOWING CROSS-SECTIONS THROUGH PRESSURE TUBE OXIDE SAMPLES IDENTIFIED IN FIGURE 4a.

(e) P3-F13, 583 cm FROM INLET
3 O'CLOCK, 1000X, MAX. OX.
THICKNESS~23 MICRONS

(f) P3-F13, 583 cm FROM INLET
12 O'CLOCK, 1000X, MAX. OX.
THICKNESS~22 MICRONS

(g) NPD-G05, 352 CM FROM INLET
12 O'CLOCK, 500X, MAX. OX.
THICKNESS~6 MICRONS

FIGURE 5(CONT): OPTICAL MICROGRAPHS SHOWING CROSS-SECTIONS THROUGH PRESSURE TUBE OXIDE SAMPLES IDENTIFIED IN FIGURE 4a.

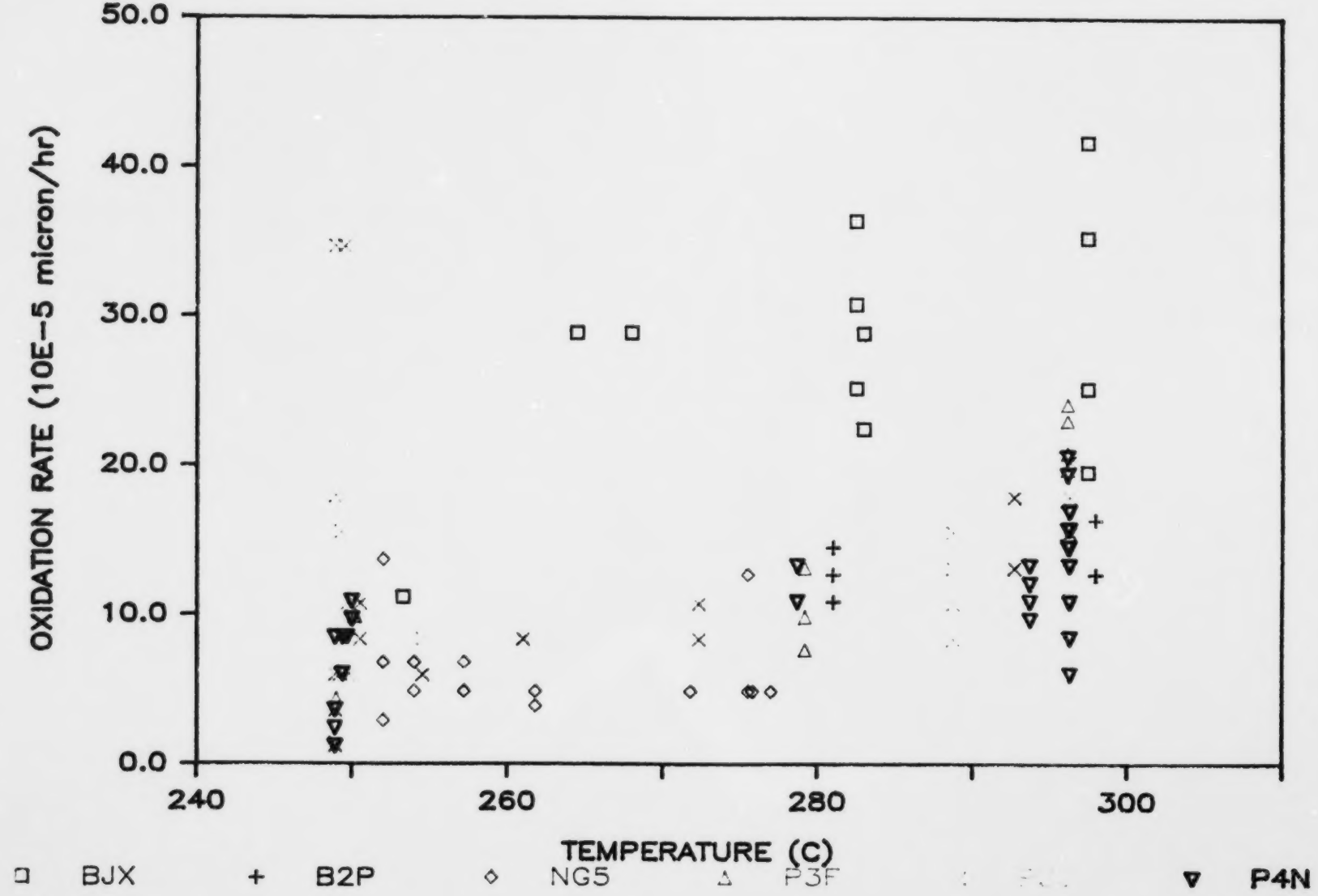


FIGURE 6a: AVERAGE MAXIMUM OXIDATION RATE VS TEMPERATURE FOR Zr-2.5% wt% Nb PRESSURE TUBES P3-F13, J09/P4-N16/B2-X14, J11, P12/NPD-G05) (FOR INITIAL OXIDE THICKNESS = 1 MICRON)

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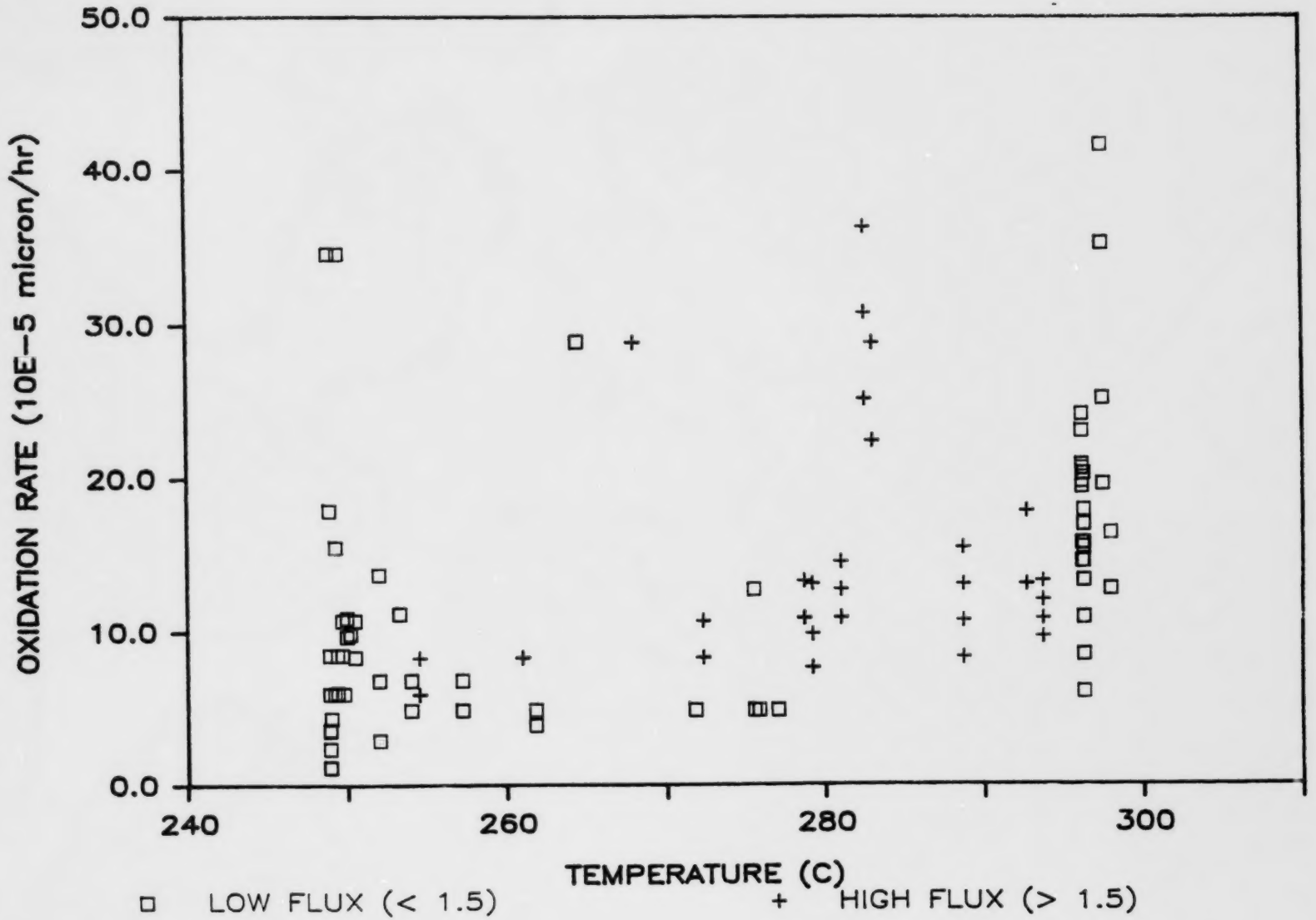

FIGURE 6b: AVERAGE MAXIMUM OXIDATION RATE VS TEMPERATURE FOR Zr-2.5 wt% Nb PRESSURE TUBES P3-F13,J09/P4-N16/B2-X14,J11,P12/NPD-G05 BY HIGH FLUX ($>1.5X10^{13}$ n/cm^2*sec) AND LOW FLUX ($<1.5X10^{13}$ n/cm^2*sec) (FOR INITIAL OXIDE THICKNESS = 1 MICRON)

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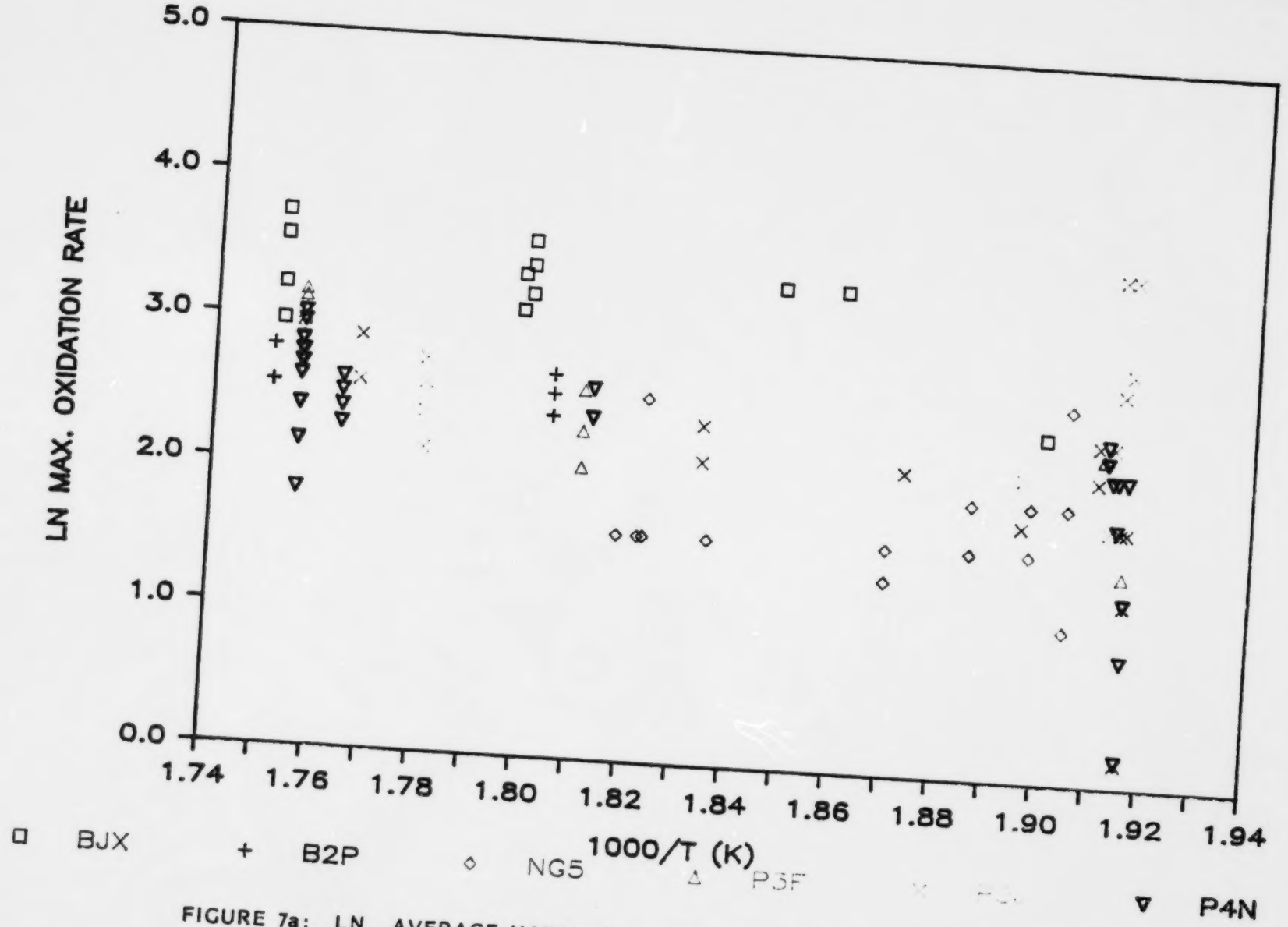

FIGURE 7a: LN AVERAGE MAXIMUM OXIDATION RATE VS 1000/T FOR Zr-2.5 wt% Nb PRESSURE TUBES P3-F13, J09/P4-N16/B2-X14, J11, P12/NPD-G05 (FOR INITIAL OXIDE THICKNESS = 1 MICRON)

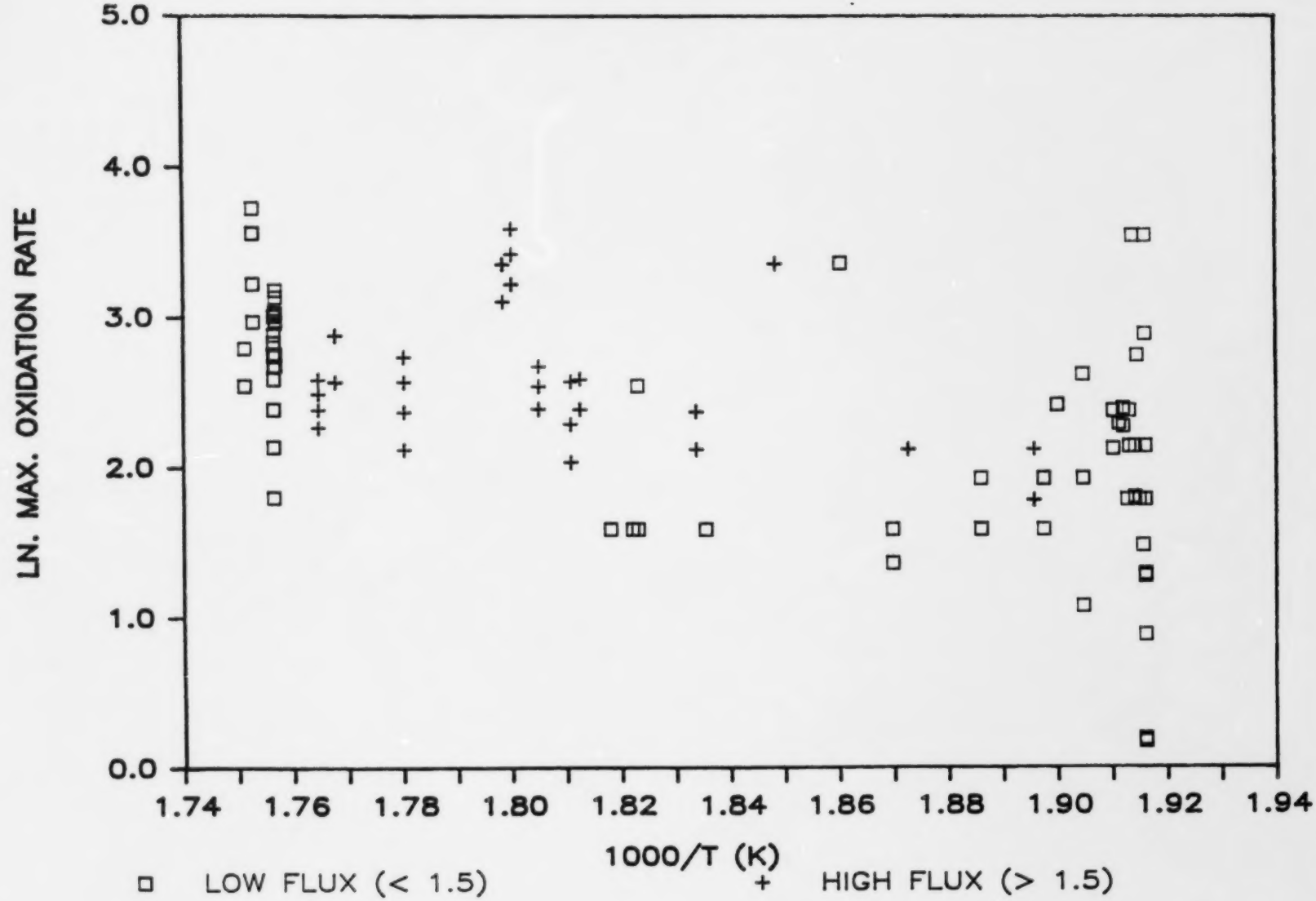

FIGURE 7b: LN AVERAGE MAXIMUM OXIDATION RATE VS 1000/T FOR Zr-2.5 wt% Nb PRESSURE TUBES P3-F13, J09/P4-N16/B2-X14, J11, P12/NPD-G05. BY HIGH FLUX ($>1.5X10^{13}$ n/cm^2*sec) AND LOW FLUX ($<1.5X10^{13}$ n/cm^2*sec) (FOR INITIAL OXIDE THICKNESS = 1 MICRON)

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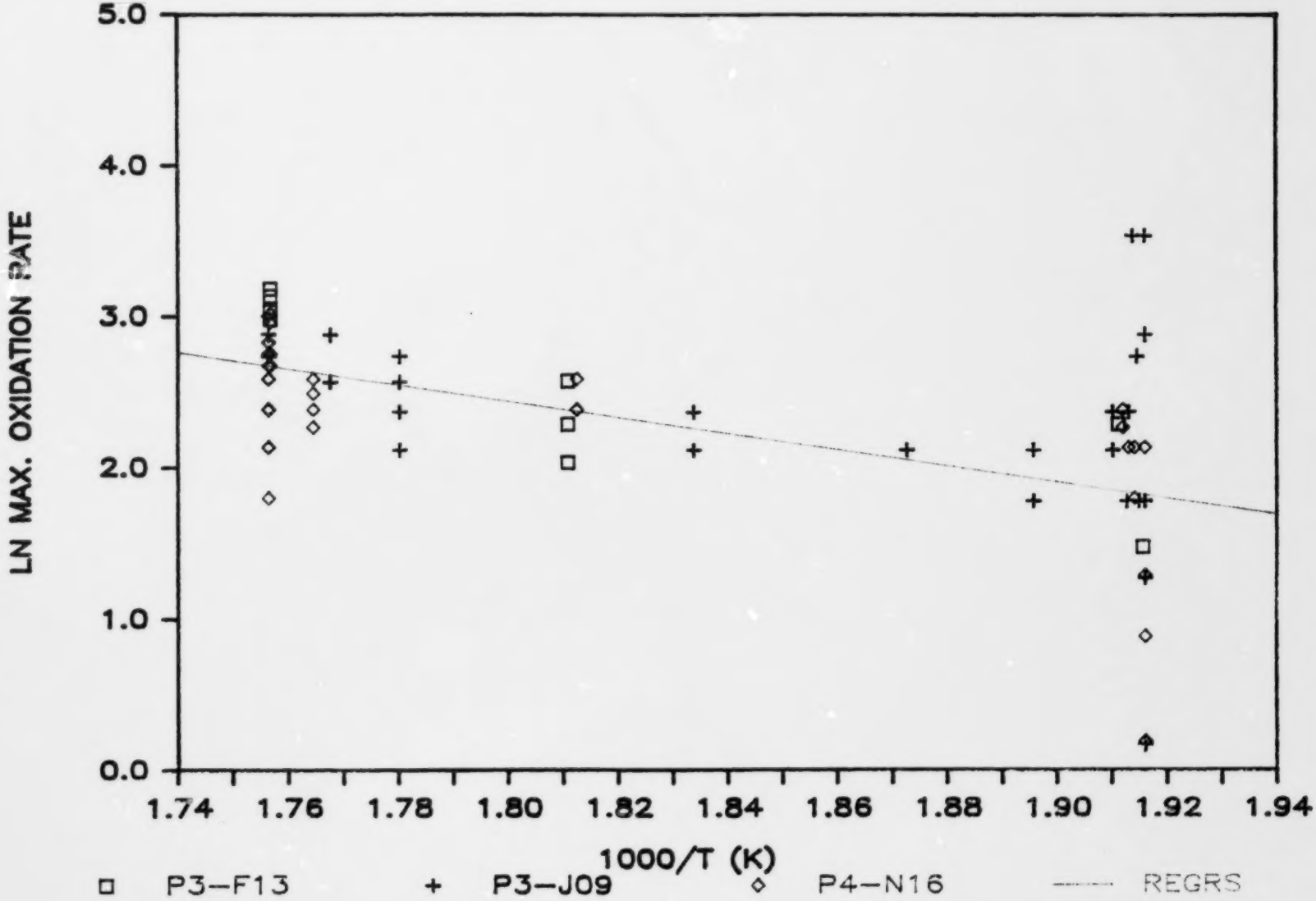

FIGURE 8a: LINEAR REGRESSION FIT OF LN MAXIMUM OXIDATION RATE VS 1000/T FOR Zr-2.5 wt% Nb PRESSURE TUBES P3-F13, J09/P4-N16

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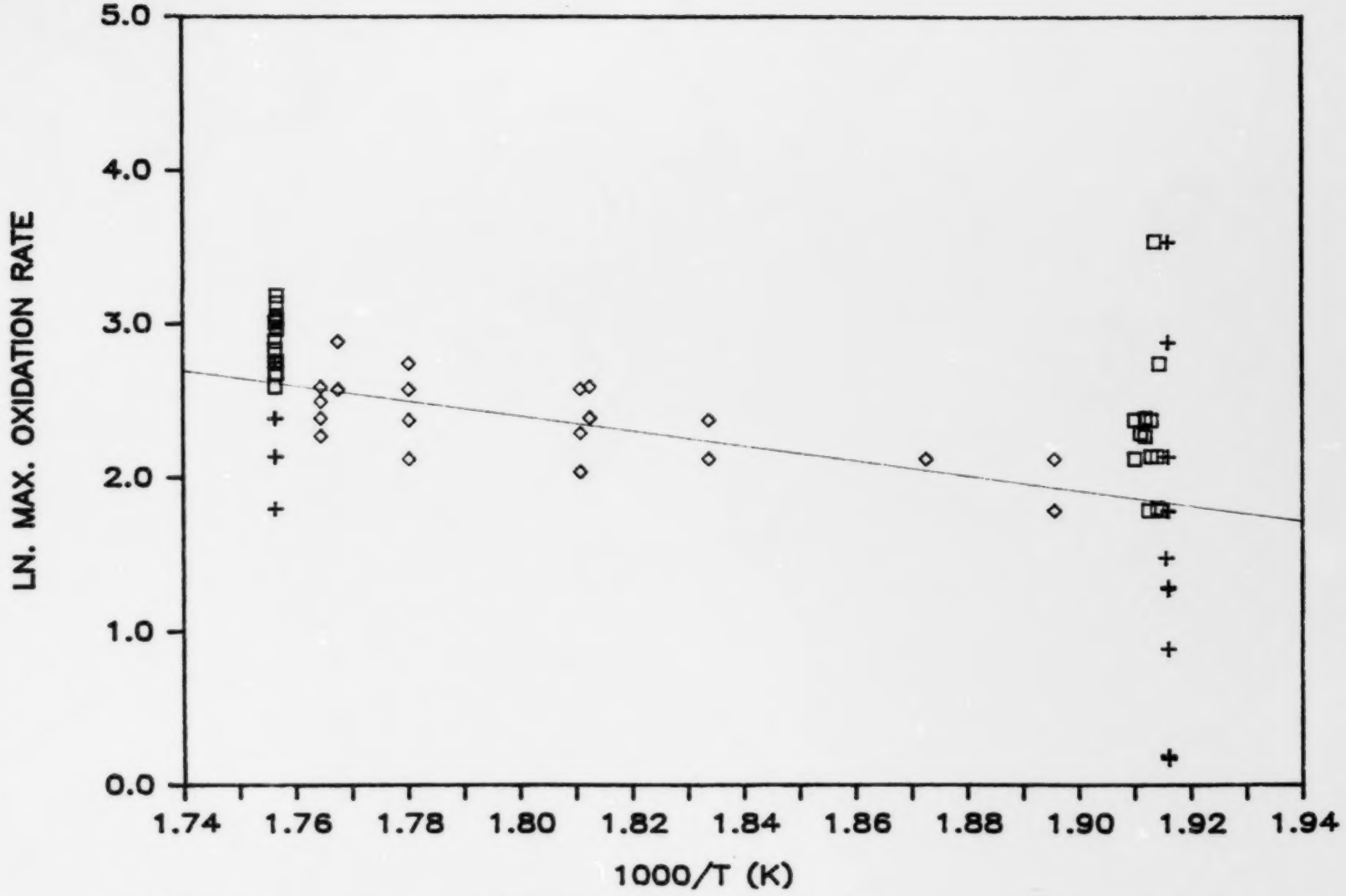

FIGURE 8b: LINEAR REGRESSION FIT OF HIGH FLUX DATA (>1.5X10^{13}n/cm^2*sec) FOR LN MAXIMUM OXIDATION RATE VS 1000/T FOR Zr-2.5 wt% Nb PRESSURE TUBES P3-F13, J09/P4-N16.

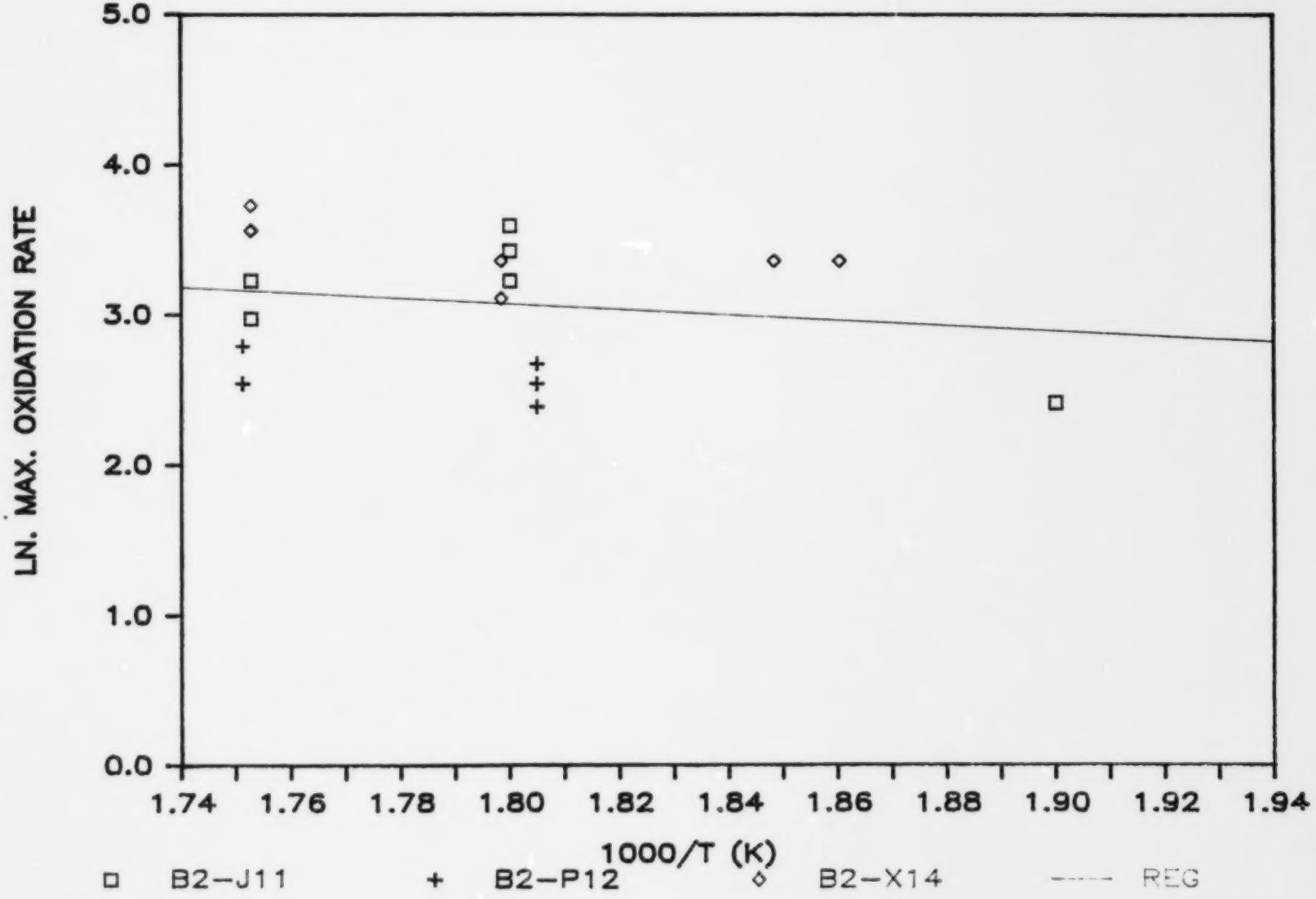

FIGURE 8c: LINEAR REGRESSION FIT OF LN MAXIMUM OXIDATION RATE VS 1000/T FOR Zr-2.5 wt% Nb PRESSURE TUBES B2-J11, P12, X14.

86-151

170895 RD

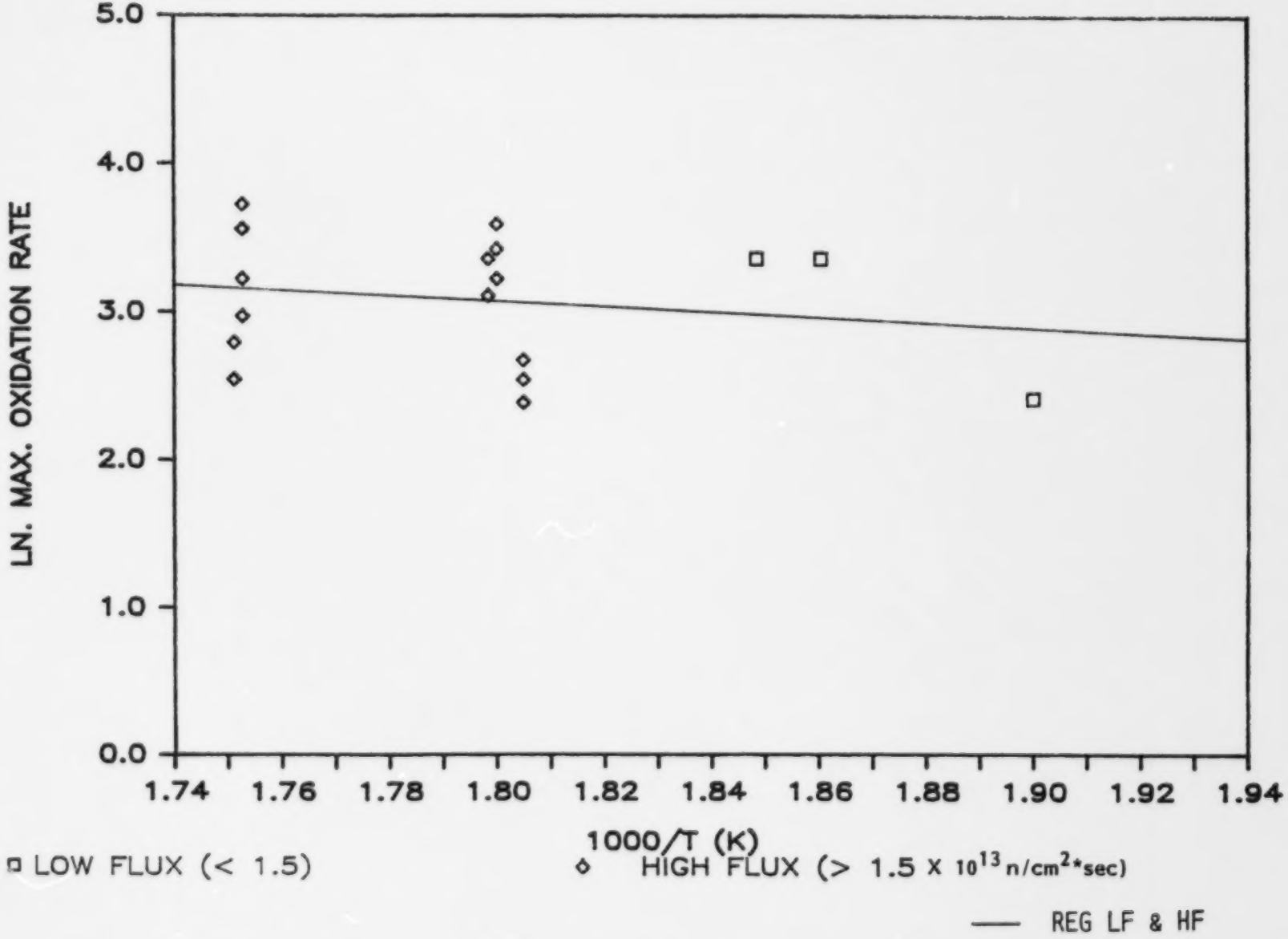

FIGURE 8d: LINEAR REGRESSION FIT OF LN MAXIMUM OXIDATION RATE VS 1000/T FOR Zr-2.5 wt% Nb PRESSURE TUBES B2-X14, J11, P12.

86-151
170896 RD

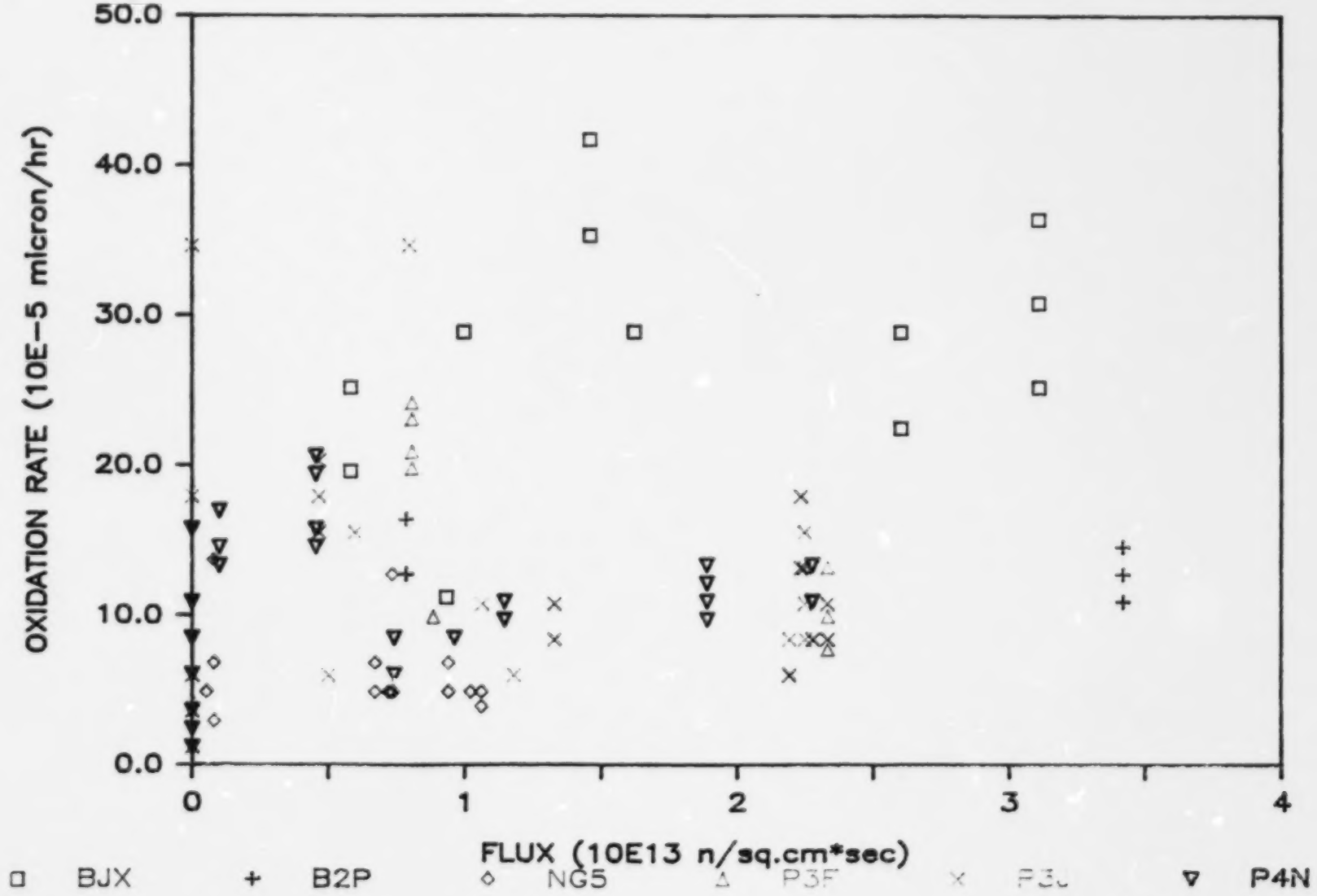

FIGURE 9a: MAXIMUM UNIFORM OXIDATION RATE VS FLUX (>1.0MeV) FOR Zr-2.5 wt% Nb PRESSURE TUBES P3-F13, J09/P4-N16/B2-X14, J11, P12/NPD-G05 (FOR INITIAL OXIDE THICKNESS = 1 MICRON)

86-151

170897 RD

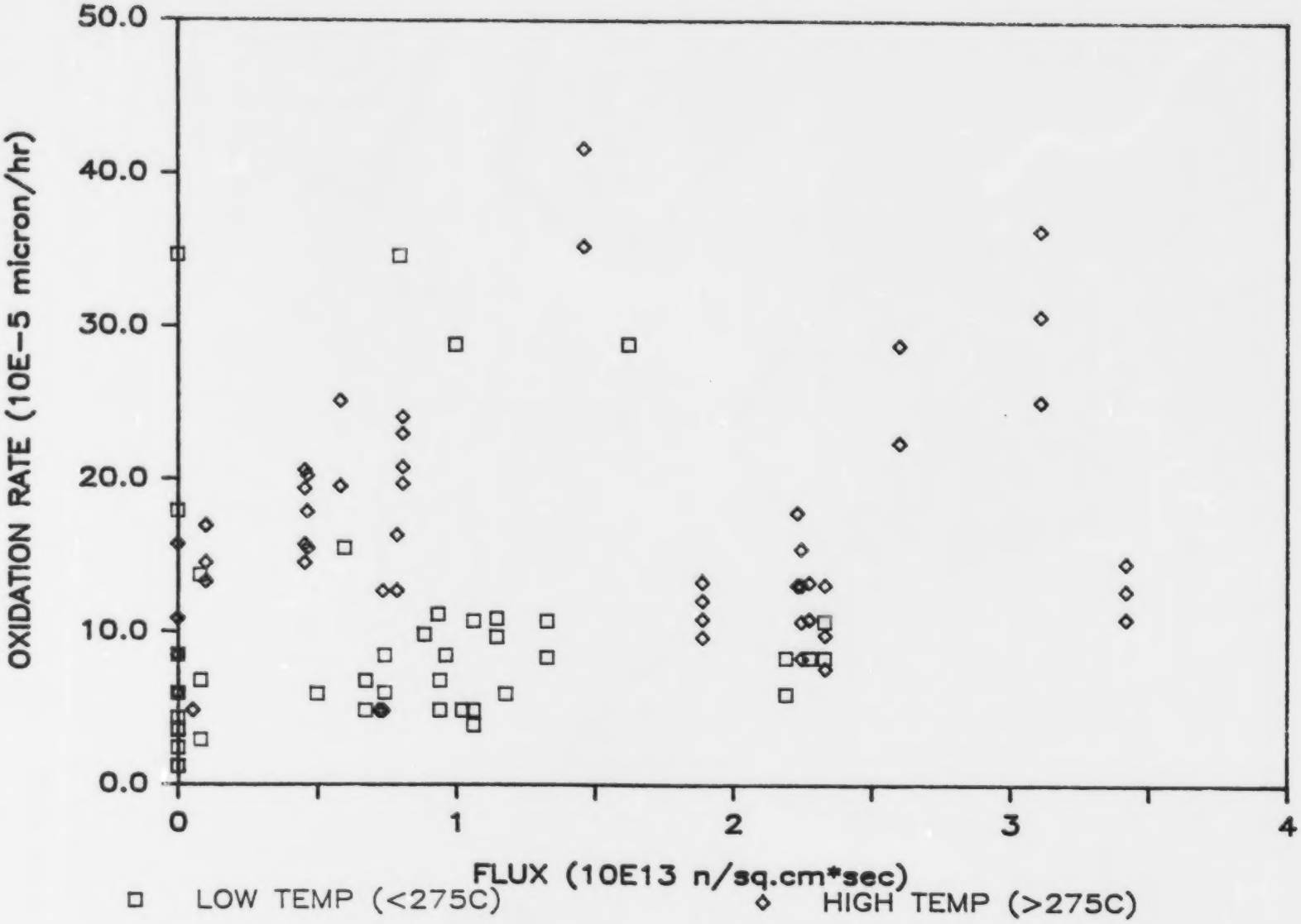

FIGURE 9b: MAXIMUM UNIFORM OXIDATION RATE VS FLUX (>1.0MeV) FOR Zr-2.5 wt% Nb PRESSURE TUBES P3-F13,J09/P4-N16/B2-X14,J11,P12/NPD-G05. (FOR INITIAL OXIDE THICKNESS = 1 MICRON)

86-151

170898 RD

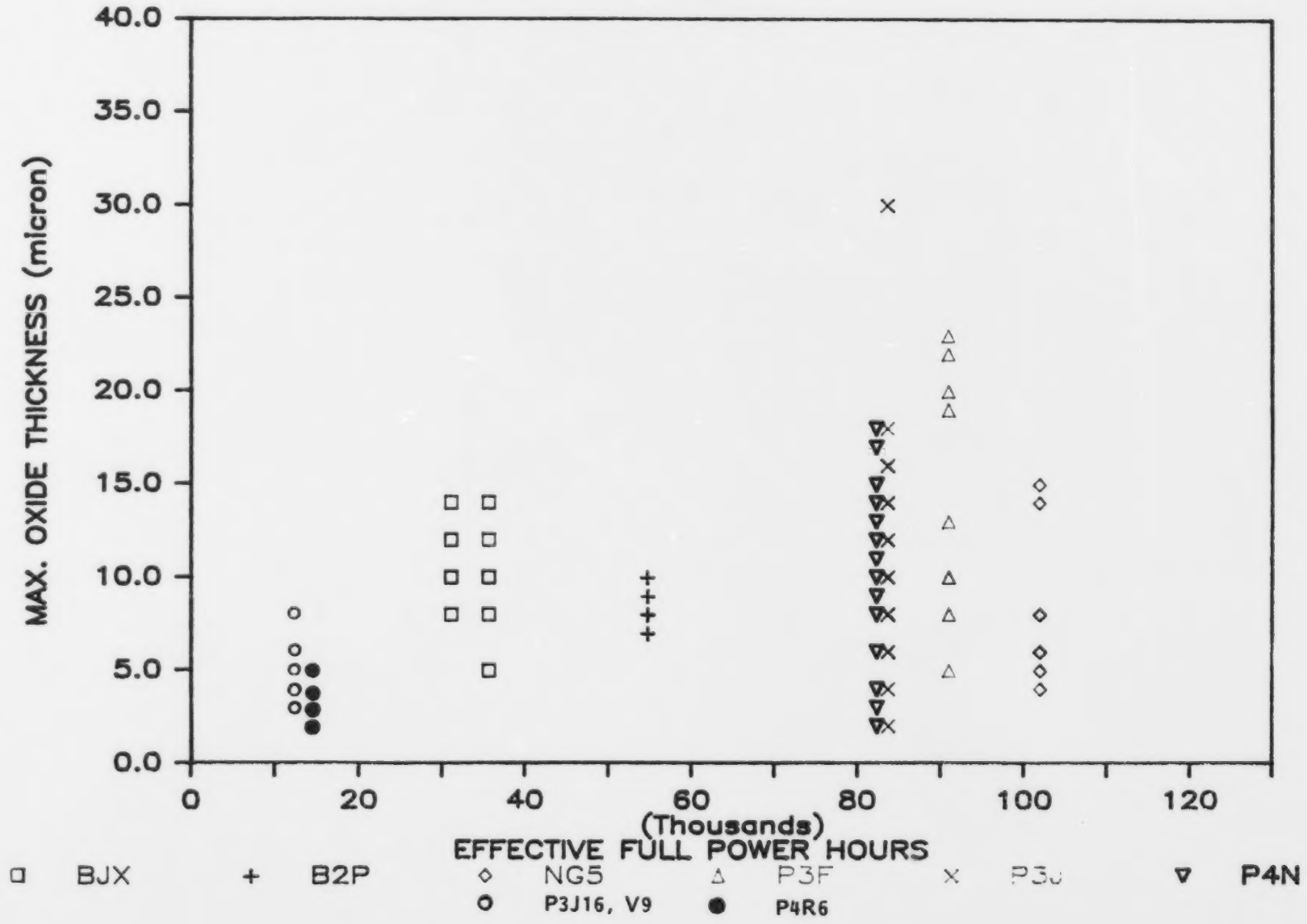

FIGURE 10a: MAXIMUM UNIFORM OXIDE THICKNESS VS EFFECTIVE FULL POWER HOURS FOR Zr-2.5 wt% Nb PRESSURE TUBES

86-151
170699 RD

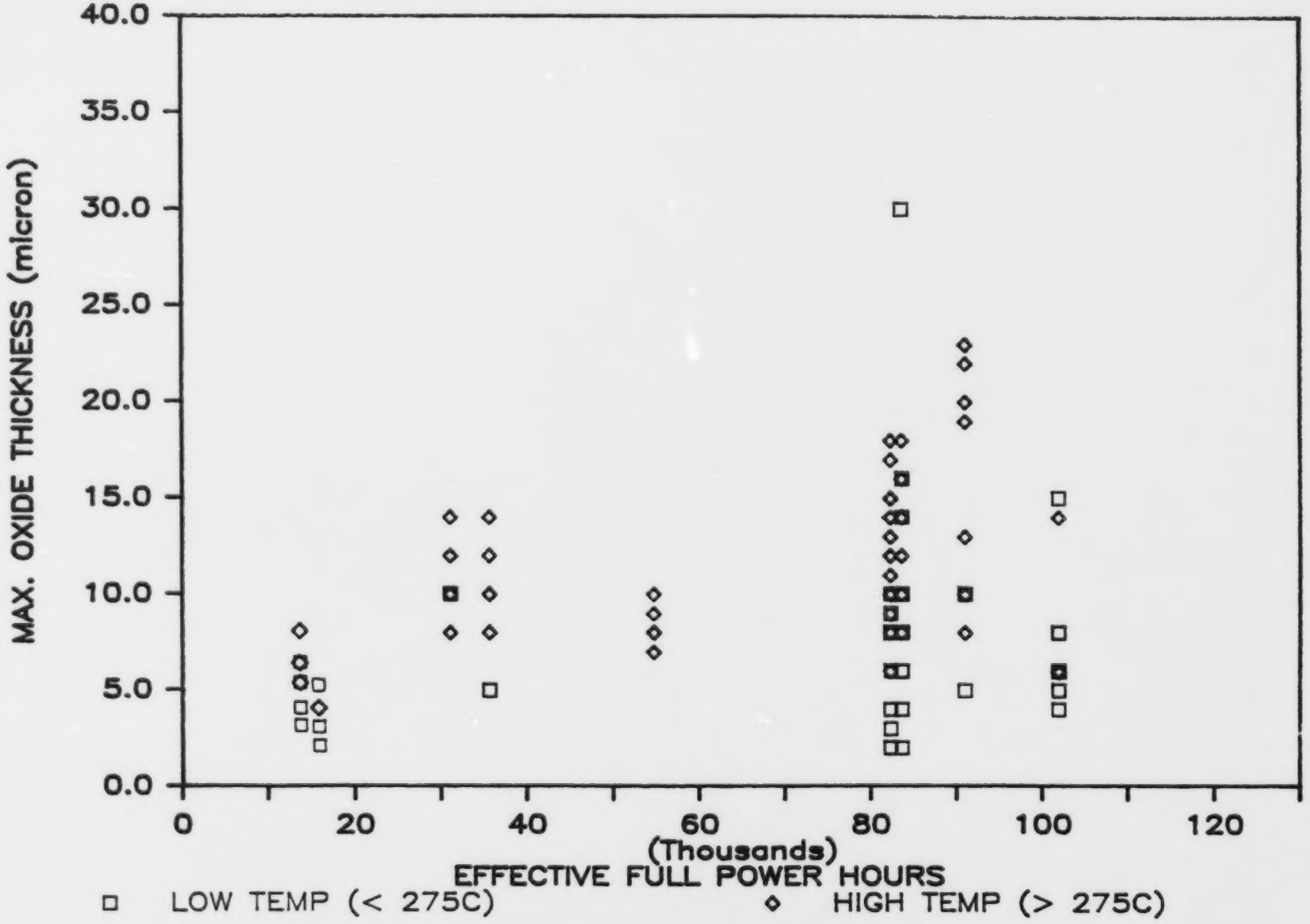

FIGURE 10b: MAXIMUM UNIFORM OXIDE THICKNESS VERSUS EFFECTIVE FULL POWER HOURS BY HIGH & LOW TEMPERATURE FOR Zr-2.5 wt% Nb PRESSURE TUBES P3-F13, J09, J16, V09/P4-N16, R06/B2-J11, X14, P12/NPD-G05.

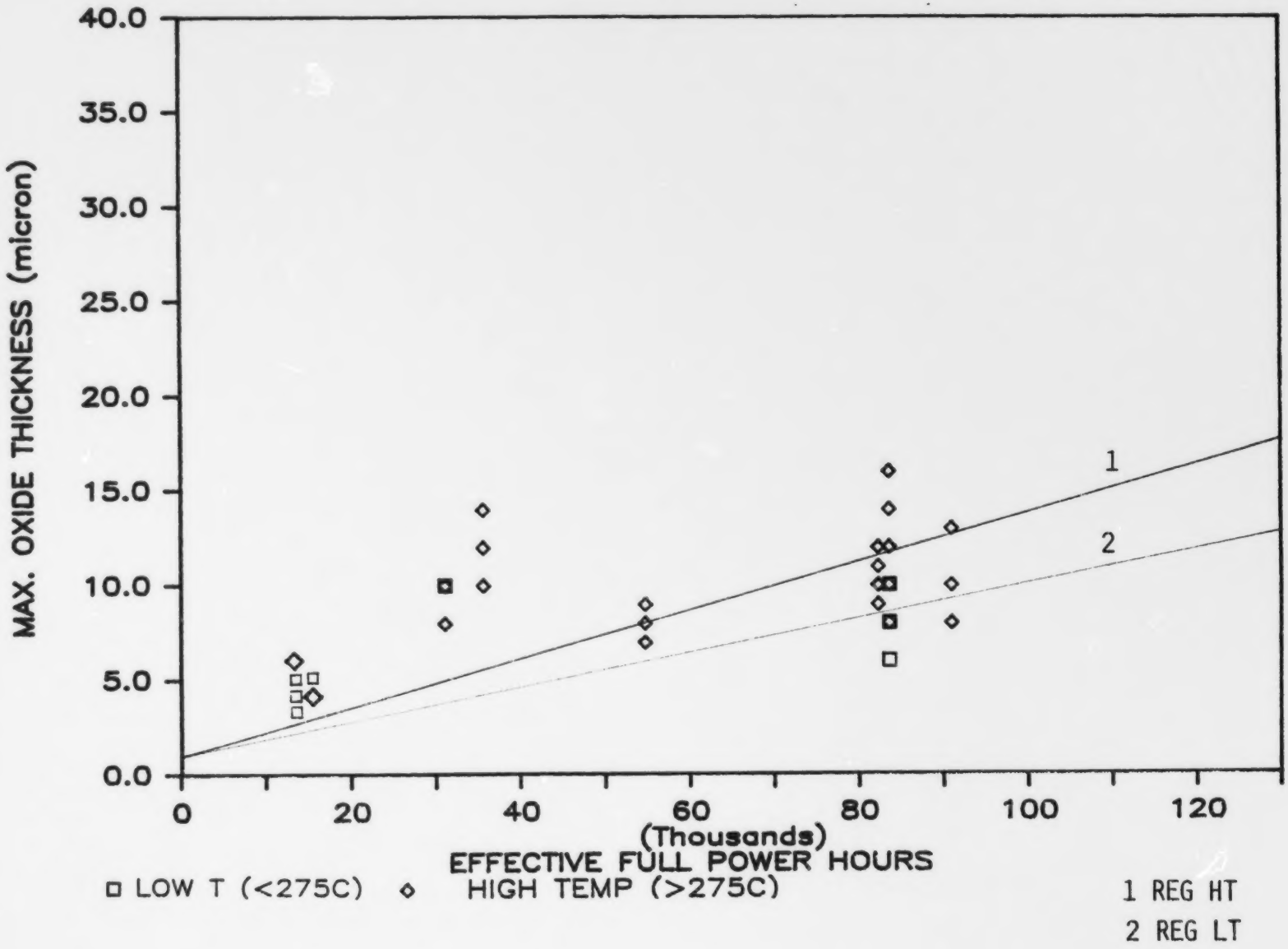

FIGURE 11a: LINEAR REGRESSION FIT OF HIGH & LOW TEMPERATURE FOR MAXIMUM UNIFORM OXIDE THICKNESS VS EFFECTIVE FULL POWER HOURS FOR Zr-2.5 wt% Nb PRESSURE TUBES P3-F13, J09, J16, V09/P4-N16, R06/B2-J11, X14, P12.
HIGH FLUX DATA ONLY ($\geq 1.5 \times 10^{13} n/cm^2 * sec$)

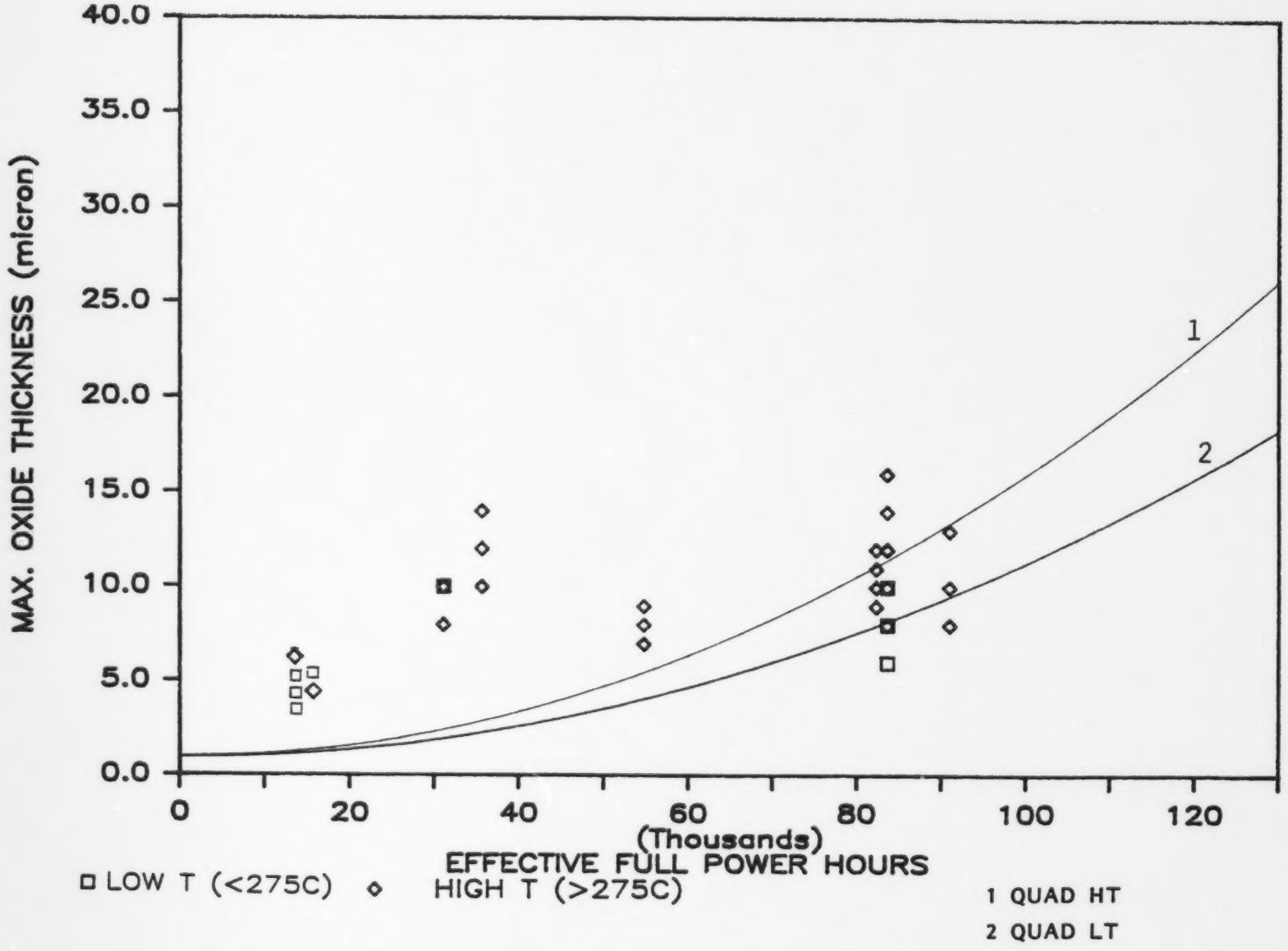

FIGURE 11b: QUADRATIC FIT OF HIGH & LOW TEMPERATURE DATA FOR MAXIMUM UNIFORM OXIDE THICKNESS VS EFFECTIVE FULL POWER HOURS FOR Zr-2.5 wt% Nb PRESSURE TUBES P3-F13, J09, J16, V09/P4-N16, R06/B2-J11, X14, P12 HIGH FLUX DATA ONLY ($>1.5X10^{13}$ n/cm^2*sec)

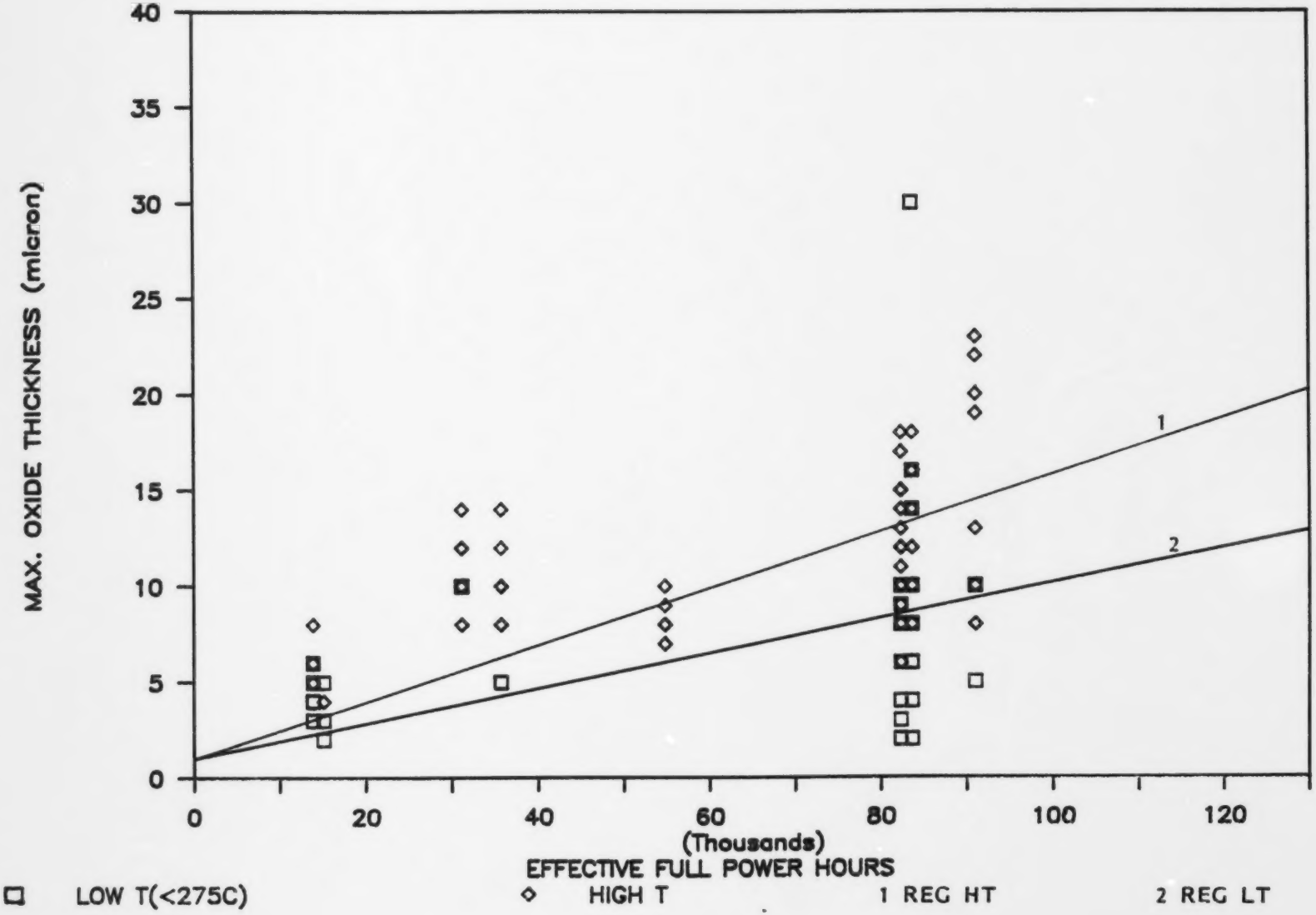

FIGURE 11c: LINEAR REGRESSION FIT OF HIGH & LOW TEMPERATURE DATA FOR MAXIMUM UNIFORM OXIDE THICKNESS VS EFFECTIVE FULL POWER HOURS FOR Zr-2.5 wt% Nb PRESSURE TUBES P3-F13,J09,J16,V09/P4-N16, R06/B2-J11,V14,P12.

86-151
170903 RD

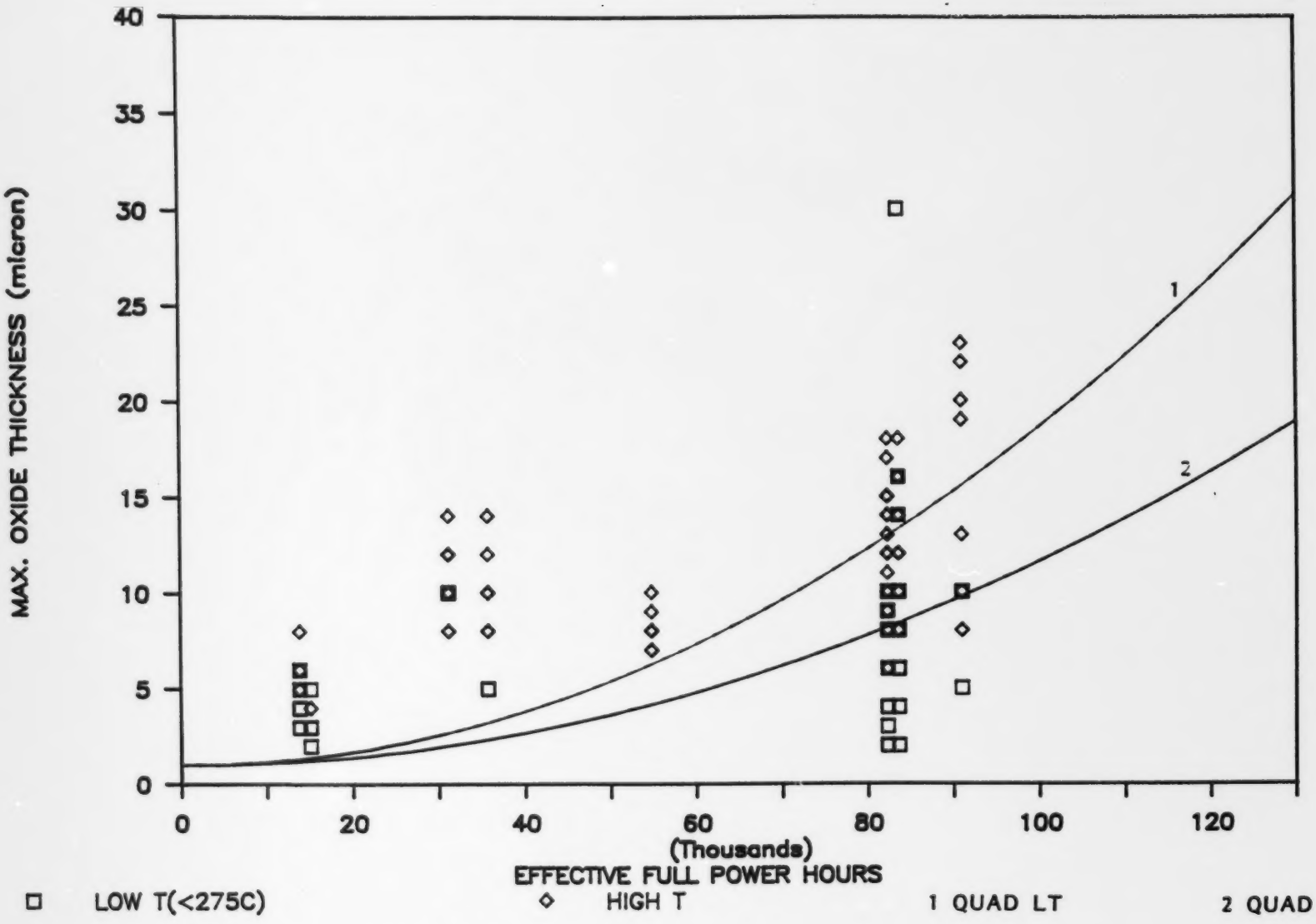

FIGURE 11d: QUADRATIC FIT OF HIGH & LOW TEMPERATURE DATA FOR MAXIMUM UNIFORM OXIDE THICKNESS VS EFFECTIVE FULL POWER HOURS FOR Zr-2.5 wt% Nb PRESSURE TUBES P3-F13,J09,J16,V09/P4-N16,R06/B2-J11,X14,P12.

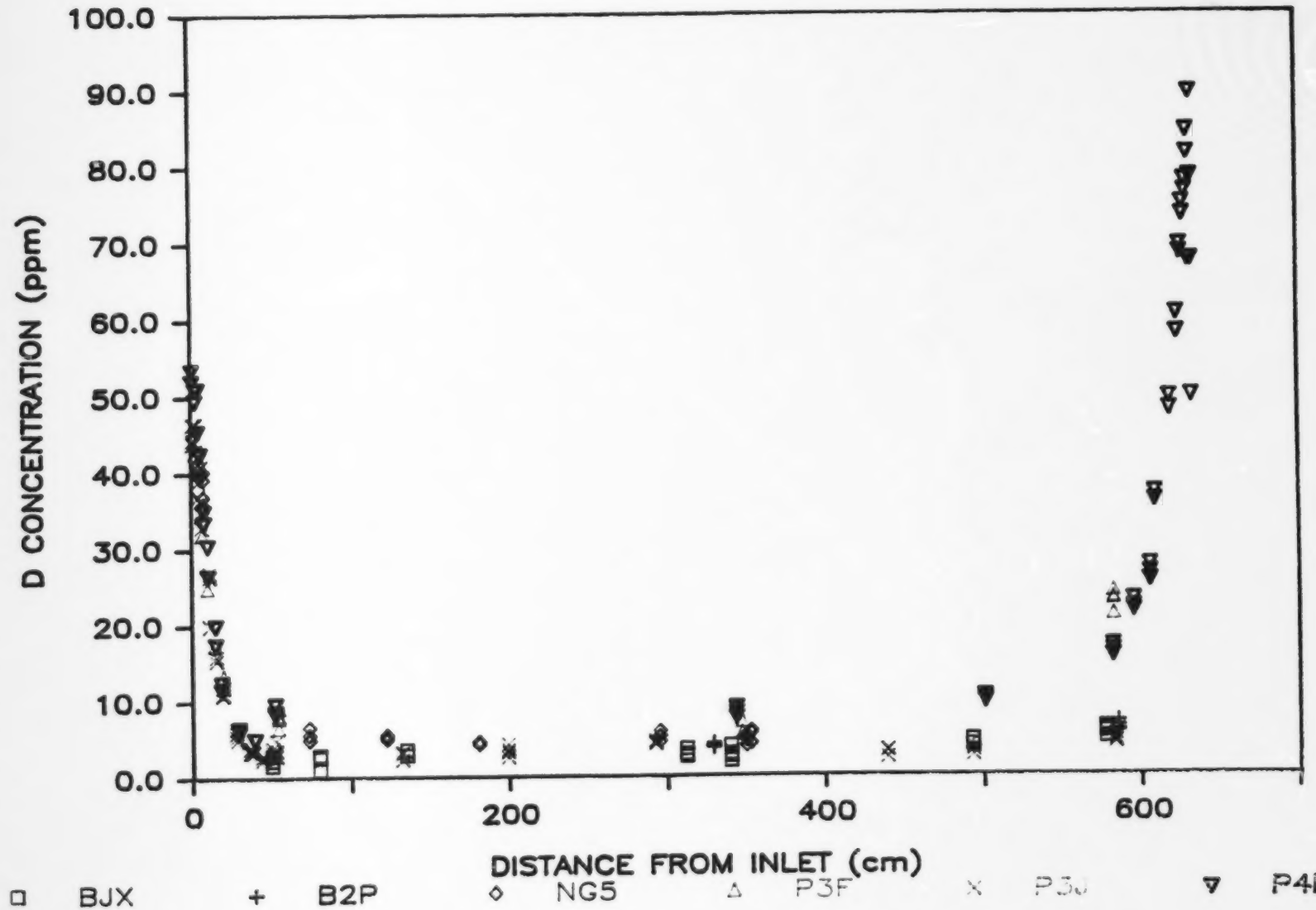

FIGURE 12a: DEUTERIUM CONCENTRATION VERSUS DISTANCE FROM INLET FOR Zr-2.5 wt% Nb PRESSURE TUBES P3-F13, J09/P4-N16/B2-J11, X14, P12/NPD-G05.

86-151

170906 RD

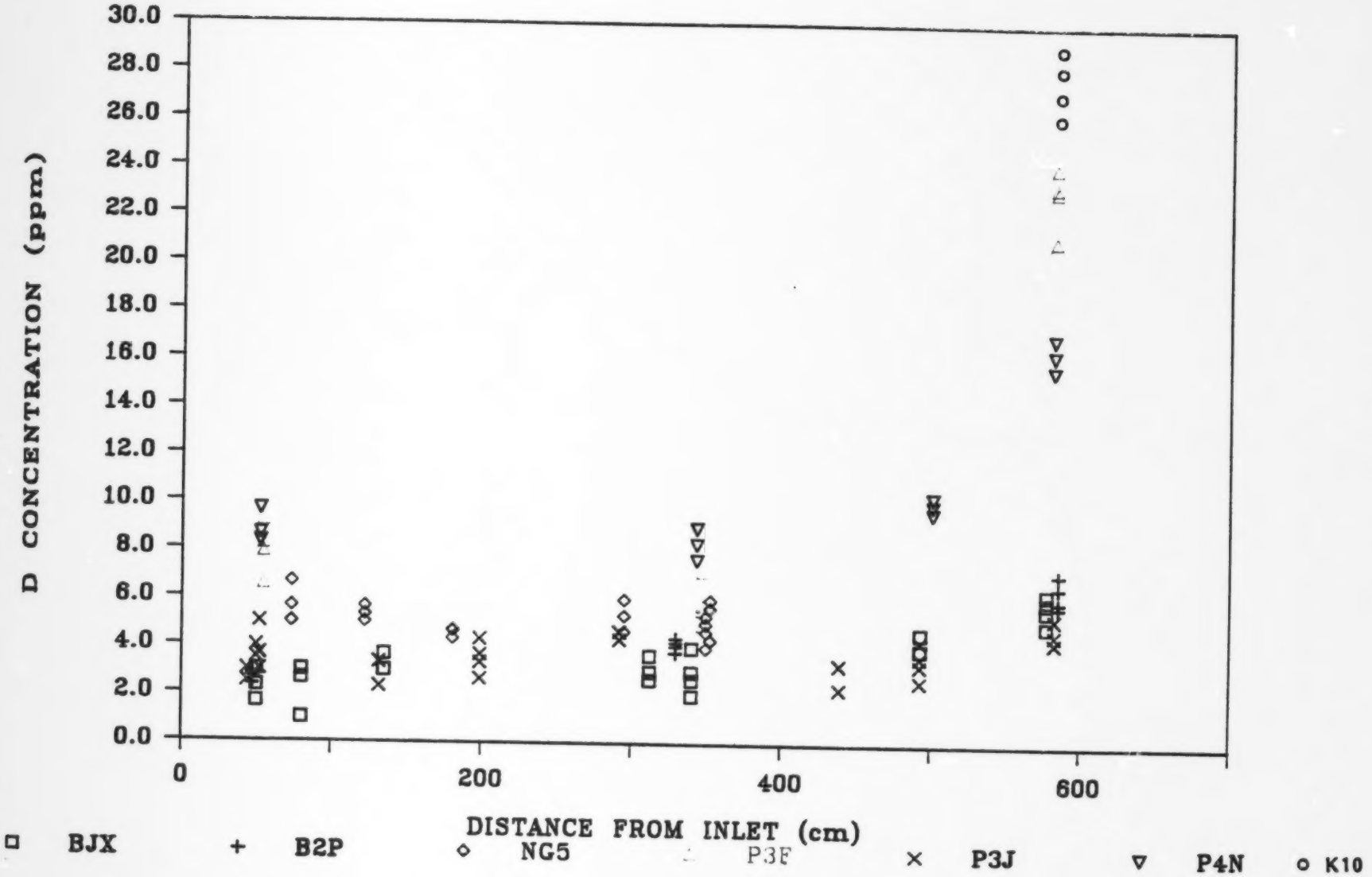

FIGURE 12b: DEUTERIUM CONCENTRATION VS DISTANCE FOR Zr-2.5 wt% Nb PRESSURE TUBES P3-F13, J09/P4-N16/B2-J11, X14, P12/NPD-G05/P4-K10. (EXCLUDING UP TO 40cm FROM PRESSURE TUBE ENDS)

86-151

170907 RD

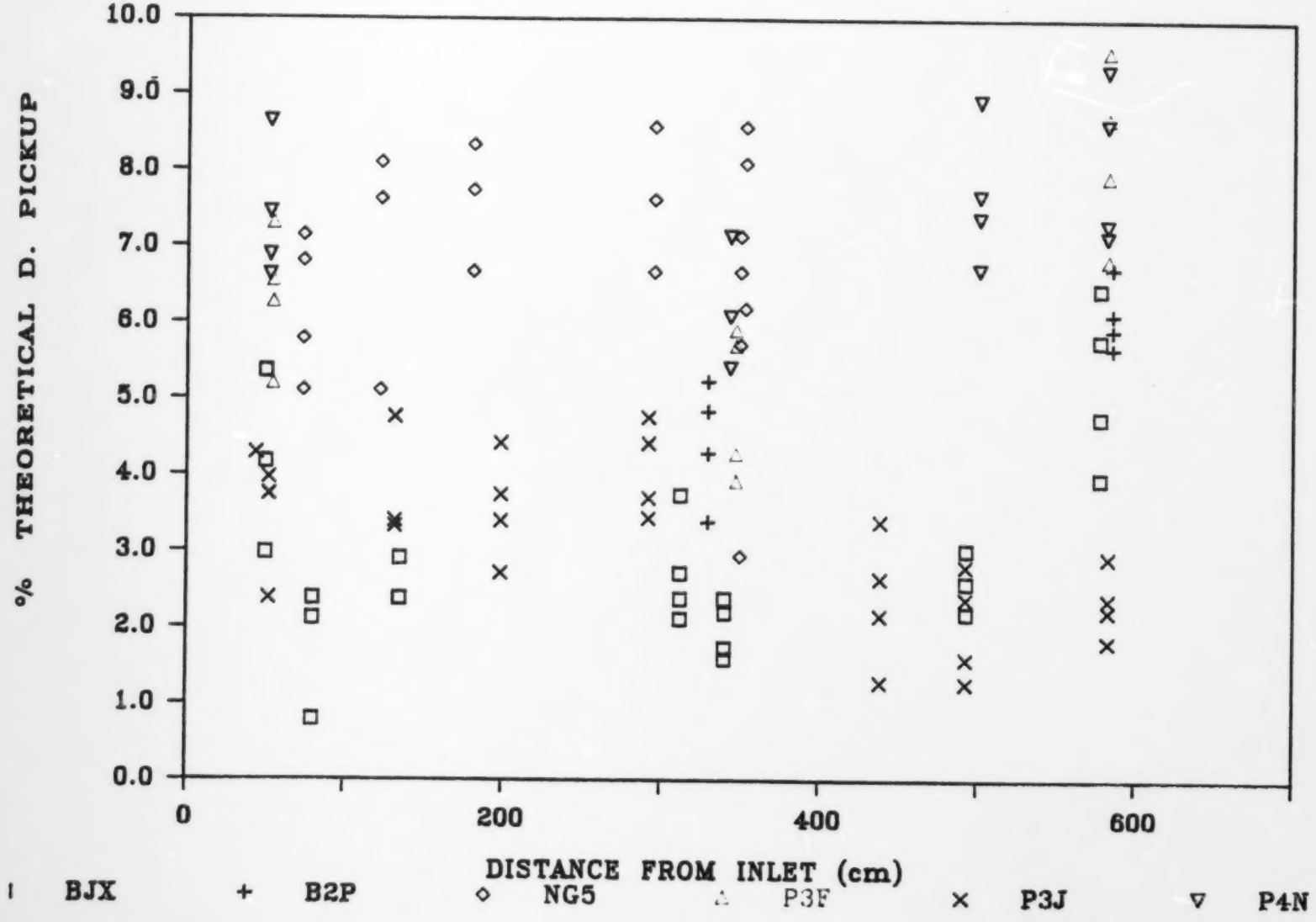

FIGURE 13a: PERCENTAGE THEORETICAL DEUTERIUM PICKUP VS DISTANCE FROM INLET FOR Zr-2.5 wt% Nb PRESSURE TUBES P3-F13, J09/P4-N16/B2-J11, X14, P12/NPD-G05. (EXCLUDING UP TO 40cm FROM PT ENDS)

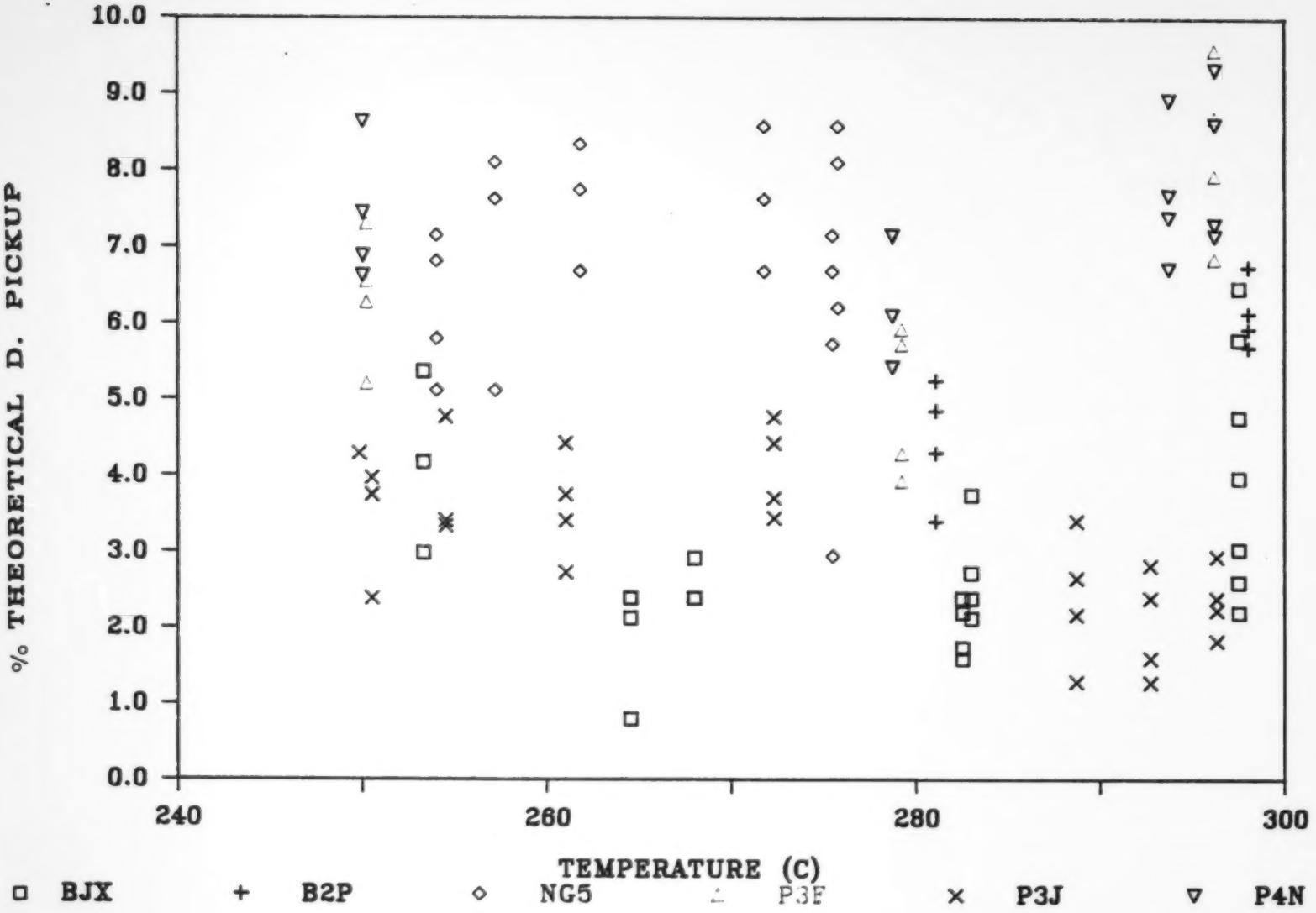

FIGURE 13b: PERCENTAGE THEORETICAL DEUTERIUM PICKUP VS TEMPERATURE FOR Zr-2.5 wt% Nb PRESSURE TUBES P3-F13,J09/P4-N16/B2-J11,X14,P12/NPD-G05. (EXCLUDING UP TO 40cm FROM PT ENDS)

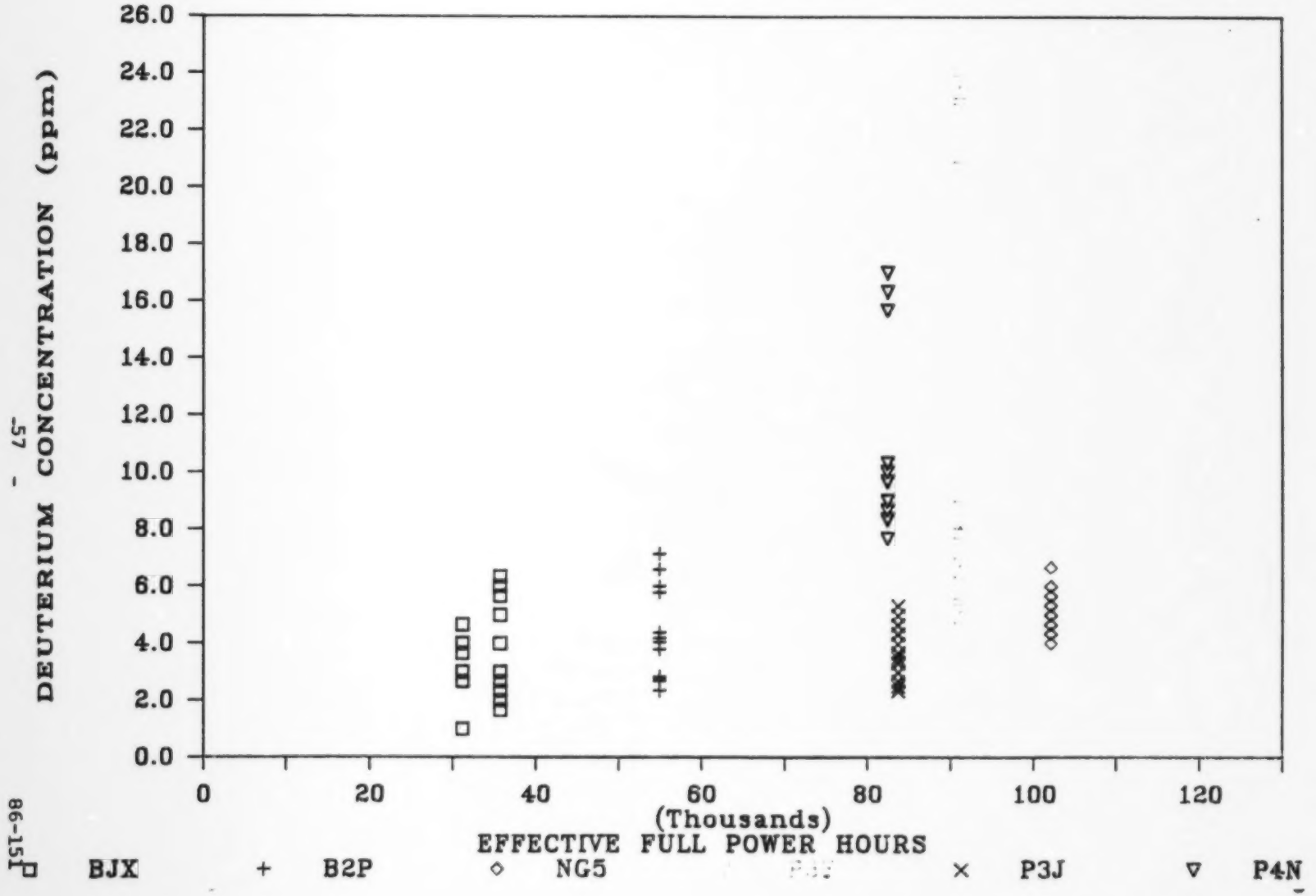

FIGURE 14a: DEUTERIUM CONCENTRATION VS EFFECTIVE FULL POWER HOURS FOR Zr-2.5 wt% Nb PRESSURE TUBES P3-F13,J09/P4-N16/B2-J11,X14,P12/NPD-G05. (EXCLUDING UP TO 40cm FROM PT ENDS)

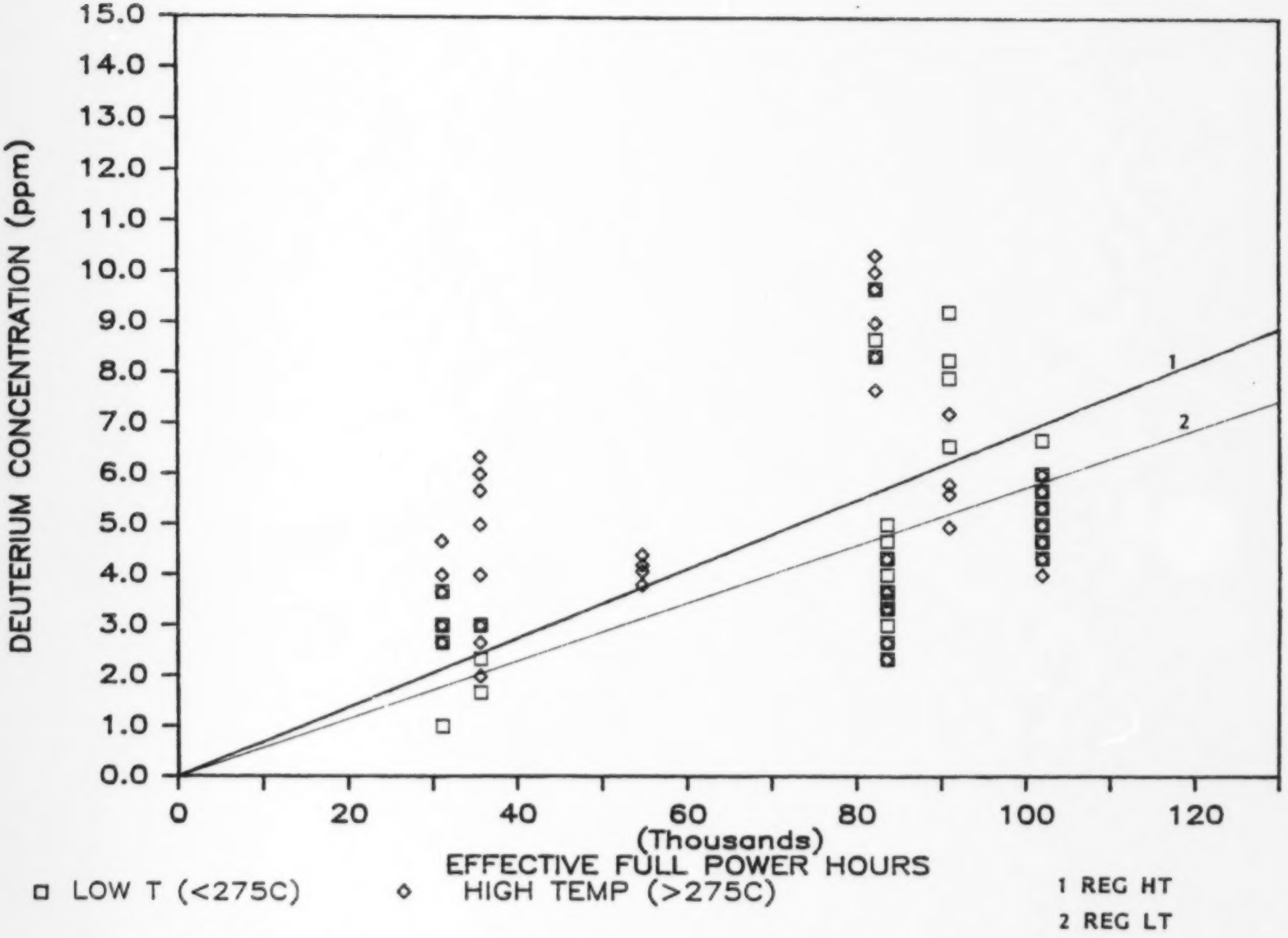

FIGURE 14b: LINEAR REGRESSION FIT OF HIGH & LOW TEMPERATURE DATA FOR DEUTERIUM CONCENTRATION VS EFFECTIVE FULL POWER HOURS FOR Zr-2.5 wt% Nb PRESSURE TUBES P3-F13,J09/P4-N16/B2-J11,X14,P12/NPD-G05. (EXCLUDING UP TO 50cm FROM PT ENDS)

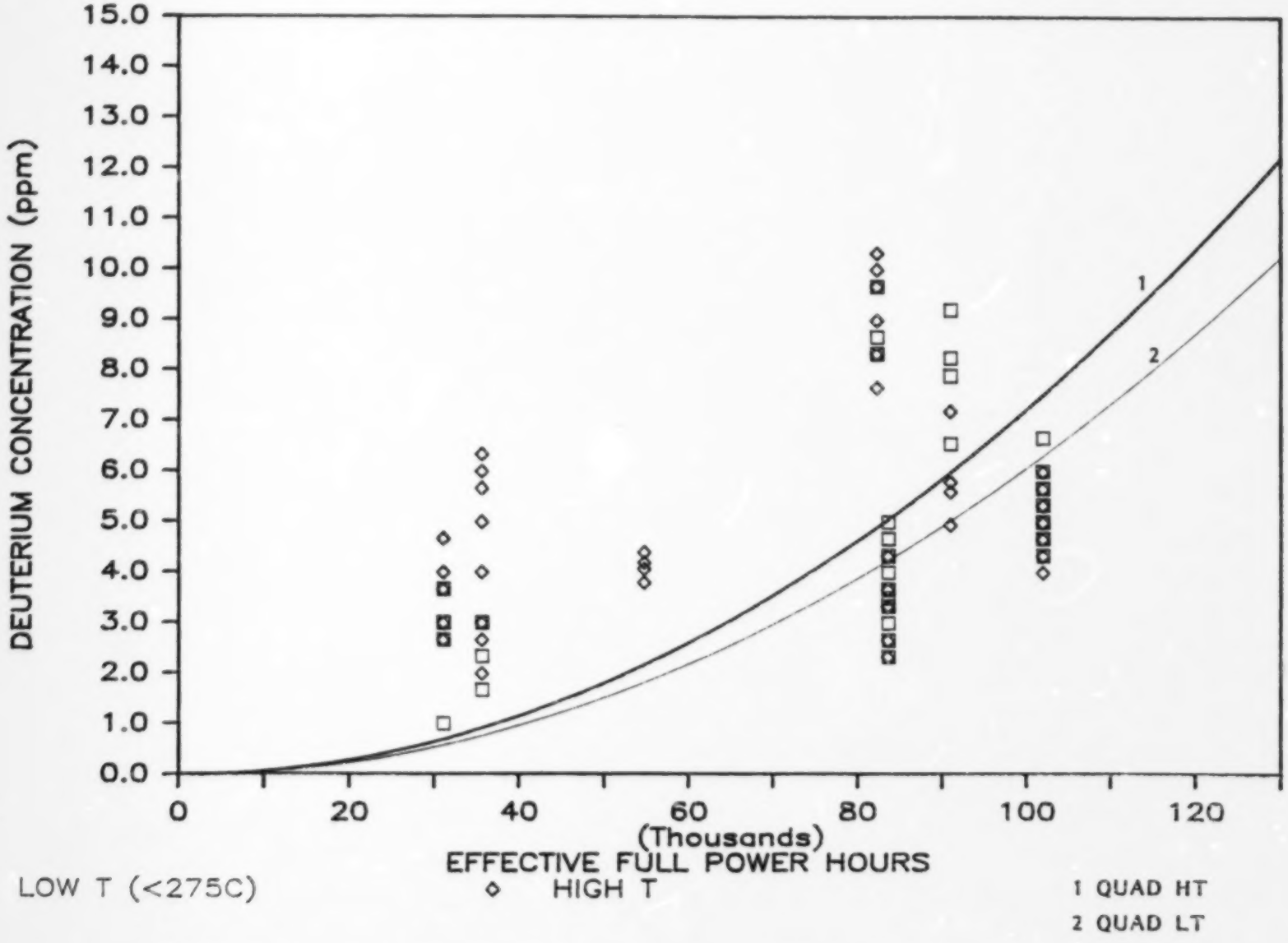

FIGURE 14c: QUADRATIC FIT OF HIGH & LOW TEMPERATURE DATA FOR DEUTERIUM CONCENTRATION VS EFFECTIVE FULL POWER HOURS FOR Zr-2.5 wt% Nb PRESSURE TUBES P3-F13, J09/P4-N16/B2-J11, X14, P12/NPD-G05. (EXCLUDING UP TO 50cm FROM PT ENDS)

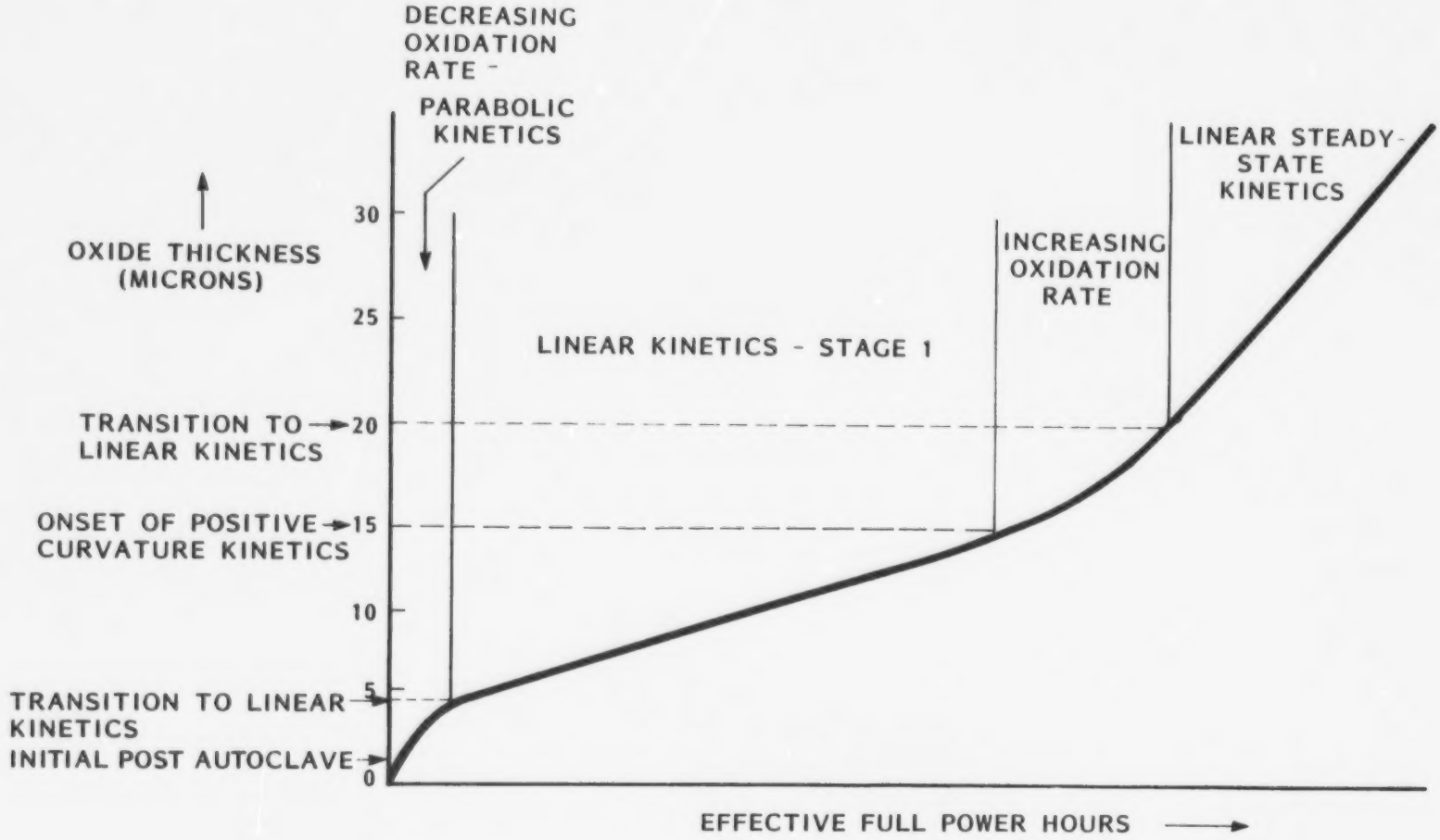

FIGURE 15: SCHEMATIC OF MOST PROBABLE RELATIONSHIP OF OXIDE THICKNESS VS EFFECTIVE FULL POWER HOURS FOR Zr-2.5 wt% Nb PRESSURE TUBES

86-151

170914 RD

APPENDIX 1: DATA BASE FOR Zr-2.5 wt% Nb PRESSURE TUBES

STN/CHL	EFPH	TEMP(C)	TEMP(K)	FLUENCE (×10²¹n/cm²)	FLUX (×10¹³n/cm²-sec)	DIS(cm)	CLOCK	D1(ppm)	D2(ppm)	D3(ppm)	DAV(ppm)	MIN_OX (μm)	MAX_OX (μm)	AVG_OX (μm)	PATCH_OX (μm)
B02 J11	3.57E+04	253.30	526.30	1.20	0.93	50.00	6.00	3.00	3.00	3.00	3.00	2.00	5.00	3.00	10.00
B02 J11	3.57E+04	253.30	526.30	1.20	0.93	50.00	12.00	1.00	1.00	3.00	1.67	2.00	5.00	3.00	14.00
B02 J11	3.57E+04	253.30	526.30	1.20	0.93	50.00	9.00	3.00	3.00	3.00	3.00	2.00	5.00	3.00	NA
B02 J11	3.57E+04	253.30	526.30	1.20	0.93	50.00	3.00	2.00	2.00	3.00	2.33	2.00	5.00	3.00	14.00
B02 J11	3.57E+04	282.50	555.50	4.00	3.11	340.00	3.00	4.00	4.00	4.00	4.00	4.00	14.00	7.00	30.00
B02 J11	3.57E+04	282.50	555.50	4.00	3.11	340.00	12.00	2.00	2.00	2.00	2.00	2.00	10.00	5.00	40.00
B02 J11	3.57E+04	282.50	555.50	4.00	3.11	340.00	6.00	2.00	2.00	4.00	2.67	4.00	12.00	7.00	54.00
B02 J11	3.57E+04	282.50	555.50	4.00	3.11	340.00	9.00	3.00	3.00	3.00	3.00	2.00	10.00	4.00	NA
B02 J11	3.57E+04	297.50	570.50	0.75	0.58	577.50	6.00	5.00	6.00	6.00	5.67	2.00	8.00	4.00	NA
B02 J11	3.57E+04	297.50	570.50	0.75	0.58	577.50	3.00	5.00	7.00	7.00	6.33	2.00	8.00	4.00	NA
B02 J11	3.57E+04	297.50	570.50	0.75	0.58	577.50	12.00	6.00	6.00	6.00	6.00	2.00	10.00	6.00	NA
B02 J11	3.57E+04	297.50	570.50	0.75	0.58	577.50	9.00	4.00	4.00	7.00	5.00	3.00	10.00	6.00	NA
B02 P12	5.48E+04	252.50	525.50	1.15	0.58	47.00	3.00	2.80	2.90	NA	2.85	NA	NA	NA	NA
B02 P12	5.48E+04	252.50	525.50	1.15	0.58	47.00	12.00	2.90	2.50	NA	2.70	NA	NA	NA	NA
B02 P12	5.48E+04	252.50	525.50	1.15	0.58	47.00	6.00	2.30	2.40	NA	2.35	NA	NA	NA	NA
B02 P12	5.48E+04	252.50	525.50	1.15	0.58	47.00	9.00	2.70	2.90	NA	2.80	NA	NA	NA	NA
B02 P12	5.48E+04	281.00	554.00	6.75	3.42	329.00	3.00	3.80	4.60	NA	4.20	2.00	8.00	5.00	23.00
B02 P12	5.48E+04	281.00	554.00	6.75	3.42	329.00	12.00	4.10	4.70	NA	4.40	2.00	7.00	5.00	12.00
B02 P12	5.48E+04	281.00	554.00	6.75	3.42	329.00	9.00	4.10	3.50	NA	3.80	2.00	9.00	5.00	15.00
B02 P12	5.48E+04	281.00	554.00	6.75	3.42	329.00	6.00	4.10	4.20	3.90	4.07	1.00	7.00	5.00	NA
B02 P12	5.48E+04	298.00	571.00	1.55	0.79	585.00	9.00	5.50	6.10	NA	5.80	3.00	8.00	5.00	13.00
B02 P12	5.48E+04	298.00	571.00	1.55	0.79	585.00	12.00	6.80	5.20	NA	6.00	3.00	8.00	5.00	11.00
B02 P12	5.48E+04	298.00	571.00	1.55	0.79	585.00	3.00	6.20	7.00	NA	6.60	2.00	8.00	5.00	11.00
B02 P12	5.48E+04	298.00	571.00	1.55	0.79	585.00	6.00	7.20	7.10	NA	7.15	2.00	10.00	8.00	NA
B02 X14	3.12E+04	264.50	537.50	1.12	1.00	80.00	6.00	4.00	2.00	2.00	2.67	3.00	10.00	5.00	20.00
B02 X14	3.12E+04	264.50	537.50	1.12	1.00	80.00	12.00	1.00	1.00	1.00	1.00	3.00	10.00	5.00	18.00
B02 X14	3.12E+04	264.50	537.50	1.12	1.00	80.00	3.00	3.00	3.00	3.00	3.00	3.00	10.00	5.00	16.00
B02 X14	3.12E+04	264.50	537.50	1.12	1.00	80.00	9.00	3.00	3.00	3.00	3.00	3.00	10.00	5.00	16.00
B02 X14	3.12E+04	268.00	541.00	1.82	1.62	135.00	9.00	3.00	5.00	3.00	3.67	4.00	10.00	5.00	NA
B02 X14	3.12E+04	268.00	541.00	1.82	1.62	135.00	3.00	3.00	3.00	3.00	3.00	4.00	10.00	6.00	NA
B02 X14	3.12E+04	268.00	541.00	1.82	1.62	135.00	12.00	3.00	3.00	3.00	3.00	4.00	10.00	6.00	16.00
B02 X14	3.12E+04	268.00	541.00	1.82	1.62	135.00	6.00	3.00	3.00	3.00	3.00	4.00	10.00	6.00	14.00
B02 X14	3.12E+04	283.00	556.00	2.92	2.60	312.00	12.00	2.00	3.00	3.00	2.67	2.00	8.00	4.00	NA
B02 X14	3.12E+04	283.00	556.00	2.92	2.60	312.00	3.00	3.00	3.00	3.00	3.00	2.00	10.00	3.00	NA
B02 X14	3.12E+04	283.00	556.00	2.92	2.60	312.00	9.00	3.00	4.00	4.00	3.67	2.00	8.00	4.00	NA
B02 X14	3.12E+04	283.00	556.00	2.92	2.60	312.00	6.00	4.00	2.00	2.00	2.67	2.00	10.00	4.00	NA
B02 X14	3.12E+04	297.50	570.50	1.64	1.46	493.00	12.00	4.00	5.00	5.00	4.67	2.00	12.00	4.00	20.00
B02 X14	3.12E+04	297.50	570.50	1.64	1.46	493.00	9.00	4.00	4.00	4.00	4.00	2.00	12.00	4.00	NA
B02 X14	3.12E+04	297.50	570.50	1.64	1.46	493.00	6.00	4.00	4.00	4.00	4.00	3.00	14.00	4.00	NA
B02 X14	3.12E+04	297.50	570.50	1.64	1.46	493.00	3.00	4.00	5.00	5.00	4.67	2.00	12.00	4.00	NA
N99 G05	1.02E+05	252.00	525.00	0.30	0.08	7.90	9.00	39.00	41.00	41.00	40.33	2.00	8.00	NA	82.00
N99 G05	1.02E+05	252.00	525.00	0.30	0.08	7.90	6.00	34.00	41.00	36.00	37.00	2.00	4.00	NA	45.00
N99 G05	1.02E+05	252.00	525.00	0.30	0.08	7.90	12.00	33.00	34.00	41.00	36.00	4.00	15.00	NA	75.00
N99 G05	1.02E+05	252.00	525.00	0.30	0.08	7.90	3.00	47.00	34.00	37.00	39.33	4.00	8.00	NA	78.00
N99 G05	1.02E+05	254.00	527.00	2.47	0.67	73.60	12.00	6.00	6.00	8.00	6.67	4.00	8.00	NA	NA
N99 G05	1.02E+05	254.00	527.00	2.47	0.67	73.60	9.00	5.00	5.00	5.00	5.00	3.00	6.00	NA	NA
N99 G05	1.02E+05	254.00	527.00	2.47	0.67	73.60	6.00	5.00	5.00	5.00	5.00	4.00	8.00	NA	NA
N99 G05	1.02E+05	254.00	527.00	2.47	0.67	73.60	3.00	6.00	5.00	6.00	5.67	3.00	8.00	NA	NA
N99 G05	1.02E+05	257.20	530.20	3.45	0.94	122.10	3.00	6.00	5.00	5.00	5.33	4.00	6.00	NA	6.00
N99 G05	1.02E+05	257.20	530.20	3.45	0.94	122.10	9.00	5.00	5.00	5.00	5.00	4.00	8.00	NA	NA
N99 G05	1.02E+05	257.20	530.20	3.45	0.94	122.10	12.00	5.00	6.00	6.00	5.67	4.00	6.00	NA	8.00
N99 G05	1.02E+05	257.20	530.20	3.45	0.94	122.10	6.00	5.00	6.00	5.00	5.33	4.00	6.00	NA	10.00
N99 G05	1.02E+05	261.80	534.80	3.90	1.06	180.70	9.00	5.00	3.00	5.00	4.33	2.00	5.00	NA	25.00
N99 G05	1.02E+05	261.80	534.80	3.90	1.06	180.70	3.00	5.00	4.00	5.00	4.67	3.00	5.00	NA	7.00
N99 G05	1.02E+05	261.80	534.80	3.90	1.06	180.70	12.00	5.00	5.00	4.00	4.67	4.00	6.00	NA	22.00
N99 G05	1.02E+05	261.80	534.80	3.90	1.06	180.70	6.00	4.00	5.00	5.00	4.67	4.00	6.00	NA	12.00
N99 G05	1.02E+05	271.80	544.80	3.75	1.02	295.00	6.00	4.00	5.00	5.00	4.67	2.00	6.00	NA	NA
N99 G05	1.02E+05	271.80	544.80	3.75	1.02	295.00	3.00	5.00	5.00	6.00	5.33	2.00	6.00	NA	NA
N99 G05	1.02E+05	271.80	544.80	3.75	1.02	295.00	12.00	5.00	5.00	6.00	5.33	1.00	6.00	NA	52.00
N99 G05	1.02E+05	271.80	544.80	3.75	1.02	295.00	9.00	6.00	6.00	6.00	6.00	2.00	6.00	NA	NA
N99 G05	1.02E+05	275.50	548.50	2.70	0.74	349.60	12.00	4.00	4.00	4.00	4.00	4.00	6.00	NA	NA
N99 G05	1.02E+05	275.50	548.50	2.70	0.74	349.60	3.00	5.00	5.00	4.00	4.67	4.00	6.00	NA	NA
N99 G05	1.02E+05	275.50	548.50	2.70	0.74	349.60	9.00	7.00	4.00	5.00	5.33	6.00	14.00	NA	30.00
N99 G05	1.02E+05	275.50	548.50	2.70	0.74	349.60	6.00	5.00	5.00	5.00	5.00	4.00	6.00	NA	56.00
N99 G05	1.02E+05	275.80	548.80	2.65	0.72	352.60	6.00	4.00	5.00	4.00	4.33	NA	NA	NA	30.00
N99 G05	1.02E+05	275.80	548.80	2.65	0.72	352.60	12.00	4.00	4.00	5.00	4.33	4.00	6.00	NA	50.00
N99 G05	1.02E+05	275.80	548.80	2.65	0.72	352.60	3.00	6.00	5.00	6.00	5.67	2.00	6.00	NA	8.00
N99 G05	1.02E+05	275.80	548.80	2.65	0.72	352.60	9.00	6.00	5.00	7.00	6.00	0.00	6.00	NA	NA

NA = NOT AVAILABLE

APPENDIX 1: DATA BASE FOR Zr-2.5 wt% Nb PRESSURE TUBES

N99	G05	1.02E+05	277.00	550.00	0.20	0.05	412.50	6.00	16.00	16.00	17.00	16.33	3.00	6.00	NA	10.00
N99	G05	1.02E+05	277.00	550.00	0.20	0.05	412.50	12.00	18.00	18.00	18.00	18.00	4.00	6.00	NA	8.00
N99	G05	1.02E+05	277.00	550.00	0.20	0.05	412.50	3.00	18.00	17.00	17.00	17.33	3.00	6.00	NA	8.00
N99	G05	1.02E+05	277.00	550.00	0.20	0.05	412.50	9.00	18.00	18.00	18.00	18.00	4.00	6.00	NA	8.00
P03	F13	9.11E+04	249.00	522.00	0.00	0.00	7.00	9.00	32.00	32.00	NA	32.00	1.00	5.00	2.00	23.00
P03	F13	9.11E+04	249.00	522.00	0.00	0.00	10.20	9.00	25.00	25.00	NA	25.00	NA	NA	NA	NA
P03	F13	9.11E+04	249.30	522.30	0.20	0.06	14.50	9.00	18.00	17.00	NA	17.50	NA	NA	NA	NA
P03	F13	9.11E+04	249.50	522.50	0.65	0.20	19.90	9.00	13.00	11.00	NA	12.00	NA	NA	NA	NA
P03	F13	9.11E+04	249.50	522.50	0.65	0.20	19.90	3.00	14.00	13.00	NA	13.50	NA	NA	NA	NA
P03	F13	9.11E+04	250.20	523.20	2.90	0.88	54.30	6.00	6.50	11.90	NA	9.20	3.00	10.00	5.00	15.00
P03	F13	9.11E+04	250.20	523.20	2.90	0.88	54.30	12.00	7.60	8.20	NA	7.90	3.00	10.00	6.00	15.00
P03	F13	9.11E+04	250.20	523.20	2.90	0.88	54.30	9.00	7.90	8.60	NA	8.25	3.00	10.00	5.00	22.00
P03	F13	9.11E+04	250.20	523.20	2.90	0.88	54.30	3.00	7.00	6.10	NA	6.55	3.00	10.00	6.00	15.00
P03	F13	9.11E+04	279.20	552.20	7.65	2.33	347.00	6.00	6.50	4.70	NA	5.60	1.00	8.00	5.00	15.00
P03	F13	9.11E+04	279.20	552.20	7.65	2.33	347.00	3.00	6.90	7.50	NA	7.20	3.00	13.00	7.00	NA
P03	F13	9.11E+04	279.20	552.20	7.65	2.33	347.00	12.00	4.80	5.10	NA	4.95	3.00	10.00	6.00	15.00
P03	F13	9.11E+04	279.20	552.20	7.65	2.33	347.00	9.00	5.10	6.50	NA	5.80	1.00	8.00	5.00	16.00
P03	F13	9.11E+04	296.20	569.20	2.65	0.81	582.60	12.00	24.30	22.40	NA	23.35	12.00	22.00	16.00	NA
P03	F13	9.11E+04	296.20	569.20	2.65	0.81	582.60	9.00	23.70	24.60	NA	24.15	10.00	19.00	15.00	NA
P03	F13	9.11E+04	296.20	569.20	2.65	0.81	582.60	6.00	24.00	22.30	NA	23.15	11.00	20.00	15.00	NA
P03	F13	9.11E+04	296.20	569.20	2.65	0.81	582.60	3.00	20.90	21.30	NA	21.10	15.00	23.00	17.00	NA
P03	J09	8.37E+04	248.90	521.90	0.00	0.00	1.00	12.00	47.00	46.00	NA	46.50	4.00	16.00	10.00	NA
P03	J09	8.37E+04	248.90	521.90	0.00	0.00	1.00	6.00	37.40	48.00	48.00	44.47	2.00	30.00	10.00	NA
P03	J09	8.37E+04	248.90	521.90	0.00	0.00	1.00	3.00	44.00	44.00	NA	44.00	NA	NA	NA	NA
P03	J09	8.37E+04	248.90	521.90	0.00	0.00	1.00	9.00	43.00	45.00	NA	44.00	NA	NA	NA	NA
P03	J09	8.37E+04	248.90	521.90	0.00	0.00	2.70	9.00	42.00	44.00	NA	43.00	NA	NA	NA	NA
P03	J09	8.37E+04	248.90	521.90	0.00	0.00	2.70	6.00	46.00	47.00	NA	46.50	1.00	6.00	2.00	NA
P03	J09	8.37E+04	248.90	521.90	0.00	0.00	2.70	12.00	43.00	43.00	NA	43.00	1.00	6.00	1.00	NA
P03	J09	8.37E+04	248.90	521.90	0.00	0.00	2.70	3.00	42.00	40.00	NA	41.00	NA	NA	NA	NA
P03	J09	8.37E+04	248.90	521.90	0.00	0.00	4.30	12.00	40.00	41.00	NA	40.50	1.00	4.00	2.00	NA
P03	J09	8.37E+04	248.90	521.90	0.00	0.00	4.30	6.00	41.00	42.00	44.00	42.33	1.00	2.00	1.00	NA
P03	J09	8.37E+04	248.90	521.90	0.00	0.00	4.30	9.00	39.00	39.00	NA	39.00	NA	NA	NA	NA
P03	J09	8.37E+04	248.90	521.90	0.00	0.00	4.30	3.00	35.00	39.00	NA	37.00	NA	NA	NA	NA
P03	J09	8.37E+04	248.90	521.90	0.00	0.00	6.10	9.00	33.00	33.00	NA	33.00	NA	NA	NA	NA
P03	J09	8.37E+04	248.90	521.90	0.00	0.00	6.10	12.00	36.00	37.00	NA	36.50	1.00	2.00	1.00	NA
P03	J09	8.37E+04	248.90	521.90	0.00	0.00	6.10	3.00	34.00	36.00	NA	35.00	NA	NA	NA	NA
P03	J09	8.37E+04	248.90	521.90	0.00	0.00	6.10	6.00	41.00	NA	NA	41.00	1.00	4.00	2.00	NA
P03	J09	8.37E+04	249.00	522.00	0.00	0.00	11.00	9.00	NA	NA	NA	NA	NA	NA	NA	NA
P03	J09	8.37E+04	249.00	522.00	0.00	0.00	11.00	12.00	27.00	26.00	NA	26.50	NA	NA	NA	NA
P03	J09	8.37E+04	249.00	522.00	0.00	0.00	11.00	6.00	27.00	NA	NA	27.00	NA	NA	NA	NA
P03	J09	8.37E+04	249.00	522.00	0.00	0.00	11.00	3.00	20.00	NA	NA	20.00	NA	NA	NA	NA
P03	J09	8.37E+04	249.20	522.20	1.50	0.50	15.00	6.00	15.00	16.00	NA	15.50	4.00	6.00	6.00	NA
P03	J09	8.37E+04	249.20	522.20	1.50	0.50	15.00	12.00	16.00	16.00	NA	16.00	NA	NA	NA	NA
P03	J09	8.37E+04	249.30	522.30	1.80	0.60	19.00	3.00	11.00	11.00	NA	11.00	NA	NA	NA	NA
P03	J09	8.37E+04	249.30	522.30	1.80	0.60	19.00	12.00	11.00	11.00	NA	11.00	NA	NA	NA	NA
P03	J09	8.37E+04	249.30	522.30	1.80	0.60	19.00	9.00	10.00	12.00	NA	11.00	NA	NA	NA	NA
P03	J09	8.37E+04	249.30	522.30	1.80	0.60	19.00	6.00	12.00	12.00	NA	12.00	2.00	14.00	7.00	NA
P03	J09	8.37E+04	249.50	522.50	2.40	0.80	27.50	6.00	7.00	6.00	NA	6.50	6.00	30.00	16.00	NA
P03	J09	8.37E+04	249.50	522.50	2.40	0.80	27.50	3.00	6.00	6.00	NA	6.00	NA	NA	NA	NA
P03	J09	8.37E+04	249.50	522.50	2.40	0.80	27.50	9.00	5.00	6.00	NA	5.50	NA	NA	NA	NA
P03	J09	8.37E+04	249.50	522.50	2.40	0.80	27.50	12.00	5.00	5.00	NA	5.00	NA	NA	NA	NA
P03	J09	8.37E+04	249.60	522.60	2.95	0.98	36.00	6.00	3.00	4.00	NA	3.50	NA	NA	NA	NA
P03	J09	8.37E+04	249.60	522.60	2.95	0.98	36.00	12.00	4.00	3.00	NA	3.50	NA	NA	NA	NA
P03	J09	8.37E+04	249.60	522.60	2.95	0.98	36.00	3.00	4.00	4.00	NA	4.00	NA	NA	NA	NA
P03	J09	8.37E+04	249.60	522.60	2.95	0.98	36.00	9.00	4.00	4.00	NA	4.00	NA	NA	NA	NA
P03	J09	8.37E+04	249.70	522.70	3.20	1.06	38.00	6.00	3.00	4.00	NA	3.50	2.00	10.00	6.00	NA
P03	J09	8.37E+04	249.70	522.70	3.20	1.06	38.00	12.00	3.00	4.00	NA	3.50	NA	NA	NA	NA
P03	J09	8.37E+04	249.80	522.80	3.55	1.18	44.00	3.00	NA	NA	NA	NA	NA	NA	NA	NA
P03	J09	8.37E+04	249.80	522.80	3.55	1.18	44.00	9.00	NA	NA	NA	NA	NA	NA	NA	NA
P03	J09	8.37E+04	249.80	522.80	3.55	1.18	44.00	12.00	3.00	2.00	NA	2.50	NA	NA	NA	NA
P03	J09	8.37E+04	249.80	522.80	3.55	1.18	44.00	6.00	2.00	4.00	NA	3.00	2.00	6.00	4.00	NA
P03	J09	8.37E+04	250.00	523.00	3.90	1.29	50.00	12.00	4.00	3.00	NA	3.50	NA	NA	NA	NA
P03	J09	8.37E+04	250.00	523.00	3.90	1.29	50.00	6.00	4.00	4.00	NA	4.00	NA	NA	NA	NA
P03	J09	8.37E+04	250.50	523.50	4.00	1.33	52.30	12.00	3.00	3.00	3.00	3.00	6.00	10.00	8.00	NA
P03	J09	8.37E+04	250.50	523.50	4.00	1.33	52.30	6.00	3.00	4.00	4.00	3.67	6.00	8.00	7.00	NA
P03	J09	8.37E+04	250.50	523.50	4.00	1.33	52.30	3.00	4.00	4.00	3.00	3.67	6.00	8.00	7.00	NA
P03	J09	8.37E+04	250.50	523.50	4.00	1.33	52.30	9.00	5.00	5.00	5.00	5.00	6.00	10.00	8.00	NA
P03	J09	8.37E+04	254.50	527.50	6.60	2.19	131.70	9.00	2.00	4.00	4.00	3.33	4.00	6.00	5.00	NA
P03	J09	8.37E+04	254.50	527.50	6.60	2.19	131.70	3.00	4.00	3.00	3.00	3.33	4.00	8.00	6.00	NA
P03	J09	8.37E+04	254.50	527.50	6.60	2.19	131.70	6.00	3.00	2.00	2.00	2.33	3.00	6.00	5.00	NA
P03	J09	8.37E+04	254.50	527.50	6.60	2.19	131.70	12.00	3.00	4.00	3.00	3.33	3.00	6.00	5.00	NA
P03	J09	8.37E+04	261.00	534.00	6.86	2.28	198.80	9.00	4.00	4.00	5.00	4.33	4.00	8.00	6.00	NA
P03	J09	8.37E+04	261.00	534.00	6.86	2.28	198.80	3.00	4.00	3.00	3.00	3.33	6.00	8.00	NA	NA

APPENDIX 1: DATA BASE FOR Zr-2.5 wt% Nb PRESSURE TUBES

P03	J09	8.37E+04	261.00	534.00	6.86	2.28	198.80	6.00	2.00	3.00	3.00	2.67	3.00	8.00	6.00	NA
P03	J09	8.37E+04	261.00	534.00	6.86	2.28	198.80	12.00	3.00	4.00	4.00	3.67	4.00	8.00	6.00	NA
P03	J09	8.37E+04	272.30	545.30	7.02	2.33	291.80	9.00	5.00	4.00	5.00	4.67	2.00	8.00	4.00	NA
P03	J09	8.37E+04	272.30	545.30	7.02	2.33	291.80	6.00	4.00	4.00	5.00	4.33	2.00	8.00	4.00	NA
P03	J09	8.37E+04	272.30	545.30	7.02	2.33	291.80	12.00	5.00	4.00	4.00	4.33	4.00	10.00	6.00	NA
P03	J09	8.37E+04	272.30	545.30	7.02	2.33	291.80	3.00	5.00	4.00	5.00	4.67	4.00	10.00	6.00	NA
P03	J09	8.37E+04	288.70	561.70	6.77	2.25	438.50	9.00	4.00	3.00	3.00	3.33	8.00	10.00	9.00	NA
P03	J09	8.37E+04	288.70	561.70	6.77	2.25	438.50	3.00	2.00	4.00	4.00	3.33	8.00	12.00	10.00	NA
P03	J09	8.37E+04	288.70	561.70	6.77	2.25	438.50	12.00	3.00	4.00	3.00	3.33	4.00	8.00	6.00	NA
P03	J09	8.37E+04	288.70	561.70	6.77	2.25	438.50	6.00	3.00	2.00	2.00	2.33	10.00	14.00	12.00	NA
P03	J09	8.37E+04	292.70	565.70	6.73	2.23	492.70	3.00	4.00	4.00	5.00	4.33	6.00	12.00	10.00	NA
P03	J09	8.37E+04	292.70	565.70	6.73	2.23	492.70	12.00	3.00	4.00	4.00	3.67	5.00	12.00	10.00	NA
P03	J09	8.37E+04	292.70	565.70	6.73	2.23	492.70	6.00	2.00	3.00	3.00	2.67	10.00	16.00	14.00	NA
P03	J09	8.37E+04	292.70	565.70	6.73	2.23	492.70	9.00	4.00	3.00	3.00	3.33	10.00	16.00	14.00	NA
P03	J09	8.37E+04	296.30	569.30	1.40	0.46	583.00	6.00	4.00	4.00	5.00	4.33	8.00	14.00	10.00	NA
P03	J09	8.37E+04	296.30	569.30	1.40	0.46	583.00	9.00	6.00	5.00	5.00	5.33	10.00	14.00	11.00	NA
P03	J09	8.37E+04	296.30	569.30	1.40	0.46	583.00	12.00	6.00	4.00	4.00	4.67	10.00	16.00	12.00	NA
P03	J16	1.38E+04	NA	NA	NA	NA	0.00	3.00	5.00	4.00	4.00	4.33	8.00	18.00	10.00	NA
P03	J16	1.38E+04	NA	NA	NA	NA	7.00	NA	NA	NA	NA	NA	1.00	4.00	NA	NA
P03	J16	1.38E+04	NA	NA	NA	NA	20.00	NA	NA	NA	NA	NA	1.00	4.00	NA	NA
P03	J16	1.38E+04	NA	NA	NA	NA	50.00	NA	NA	NA	NA	NA	1.00	5.00	NA	NA
P03	J16	1.38E+04	NA	NA	NA	NA	75.00	NA	NA	NA	NA	NA	2.00	6.00	NA	NA
P03	J16	1.38E+04	NA	NA	NA	NA	155.00	NA	NA	NA	NA	NA	2.00	4.00	NA	NA
P03	J16	1.38E+04	NA	NA	NA	NA	180.00	NA	NA	NA	NA	NA	2.00	4.00	NA	NA
P03	V09	1.38E+04	NA	NA	NA	NA	20.00	NA	NA	NA	NA	NA	2.00	4.00	NA	NA
P03	V09	1.38E+04	NA	NA	NA	NA	115.00	NA	NA	NA	NA	NA	1.00	3.00	NA	NA
P03	V09	1.38E+04	NA	NA	NA	NA	310.00	NA	NA	NA	NA	NA	1.00	3.00	NA	NA
P03	V09	1.38E+04	NA	NA	NA	NA	460.00	NA	NA	NA	NA	NA	2.00	6.00	NA	NA
P03	V09	1.38E+04	NA	NA	NA	NA	590.00	NA	NA	NA	NA	NA	3.00	5.00	NA	NA
P04	N16	8.24E+04	248.90	521.90	0.00	0.00	0.80	6.00	53.00	54.00	NA	53.50	3.00	8.00	NA	NA
P04	N16	8.24E+04	248.90	521.90	0.00	0.00	0.80	12.00	52.00	52.00	NA	52.00	1.00	2.00	1.00	NA
P04	N16	8.24E+04	248.90	521.90	0.00	0.00	2.70	12.00	49.00	50.00	NA	49.50	2.00	8.00	4.00	16.00
P04	N16	8.24E+04	248.90	521.90	0.00	0.00	2.70	6.00	51.00	51.00	NA	51.00	1.00	2.00	2.00	NA
P04	N16	8.24E+04	248.90	521.90	0.00	0.00	4.40	6.00	51.00	51.00	NA	51.00	NA	NA	NA	NA
P04	N16	8.24E+04	248.90	521.90	0.00	0.00	4.40	12.00	46.00	45.00	NA	45.50	2.00	4.00	2.00	NA
P04	N16	8.24E+04	248.90	521.90	0.00	0.00	6.00	6.00	40.00	39.00	NA	39.50	1.00	3.00	2.00	NA
P04	N16	8.24E+04	248.90	521.90	0.00	0.00	6.00	12.00	43.00	42.00	NA	42.50	NA	NA	NA	NA
P04	N16	8.24E+04	248.90	521.90	0.00	0.00	8.00	6.00	35.00	35.00	NA	35.00	NA	NA	NA	NA
P04	N16	8.24E+04	248.90	521.90	0.00	0.00	8.00	12.00	34.00	33.00	NA	33.50	1.00	2.00	2.00	NA
P04	N16	8.24E+04	249.00	522.00	0.75	0.25	10.10	6.00	26.00	27.00	NA	26.50	2.00	4.00	3.00	NA
P04	N16	8.24E+04	249.00	522.00	0.75	0.25	10.10	12.00	30.00	31.00	NA	30.50	NA	NA	NA	NA
P04	N16	8.24E+04	249.20	522.20	1.15	0.39	15.00	6.00	17.00	18.00	NA	17.50	NA	NA	NA	NA
P04	N16	8.24E+04	249.20	522.20	1.15	0.39	15.00	12.00	20.00	20.00	NA	20.00	NA	NA	NA	NA
P04	N16	8.24E+04	249.20	522.20	1.55	0.52	18.50	6.00	11.00	12.00	NA	11.50	NA	NA	NA	NA
P04	N16	8.24E+04	249.20	522.20	1.55	0.52	18.50	12.00	12.00	13.00	NA	12.50	NA	NA	NA	NA
P04	N16	8.24E+04	249.40	522.40	2.20	0.74	29.40	6.00	6.00	6.00	NA	6.00	4.00	6.00	5.00	NA
P04	N16	8.24E+04	249.40	522.40	2.20	0.74	29.40	12.00	7.00	6.00	NA	6.50	4.00	8.00	7.00	NA
P04	N16	8.24E+04	249.70	522.70	2.85	0.96	39.40	6.00	5.00	5.00	NA	5.00	4.00	8.00	6.00	NA
P04	N16	8.24E+04	249.70	522.70	2.85	0.96	39.40	12.00	5.00	5.00	NA	5.00	6.00	8.00	7.00	NA
P04	N16	8.24E+04	250.00	523.00	3.40	1.15	52.30	9.00	9.00	9.00	11.00	9.67	3.00	9.00	5.00	NA
P04	N16	8.24E+04	250.00	523.00	3.40	1.15	52.30	3.00	9.00	8.00	9.00	8.67	3.00	10.00	5.00	NA
P04	N16	8.24E+04	250.00	523.00	3.40	1.15	52.30	12.00	9.00	8.00	8.00	8.33	3.00	9.00	5.00	NA
P04	N16	8.24E+04	250.00	523.00	3.40	1.15	52.30	6.00	8.00	9.00	8.00	8.33	3.00	10.00	5.00	NA
P04	N16	8.24E+04	278.70	551.70	6.75	2.28	343.20	6.00	7.00	8.00	8.00	7.67	4.00	10.00	6.00	15.00
P04	N16	8.24E+04	278.70	551.70	6.75	2.28	343.20	9.00	8.00	9.00	8.00	8.33	4.00	12.00	6.00	17.00
P04	N16	8.24E+04	278.70	551.70	6.75	2.28	343.20	3.00	9.00	9.00	9.00	9.00	4.00	10.00	6.00	NA
P04	N16	8.24E+04	278.70	551.70	6.75	2.28	343.20	12.00	9.00	9.00	9.00	9.00	4.00	10.00	6.00	12.00
P04	N16	8.24E+04	293.70	566.70	5.60	1.89	500.80	6.00	10.00	11.00	10.00	10.33	6.00	12.00	8.00	17.00
P04	N16	8.24E+04	293.70	566.70	5.60	1.89	500.80	9.00	9.00	10.00	10.00	9.67	3.00	10.00	6.00	16.00
P04	N16	8.24E+04	293.70	566.70	5.60	1.89	500.80	3.00	10.00	10.00	11.00	10.33	5.00	11.00	8.00	15.00
P04	N16	8.24E+04	293.70	566.70	5.60	1.89	500.80	12.00	10.00	10.00	10.00	10.00	4.00	9.00	7.00	15.00
P04	N16	8.24E+04	296.20	569.20	1.35	0.46	581.70	3.00	17.00	17.00	17.00	17.00	6.00	18.00	11.00	NA
P04	N16	8.24E+04	296.20	569.20	1.35	0.46	581.70	9.00	16.00	16.00	15.00	15.67	5.00	13.00	9.00	NA
P04	N16	8.24E+04	296.20	569.20	1.35	0.46	581.70	6.00	16.00	16.00	17.00	16.33	6.00	17.00	10.00	NA
P04	N16	8.24E+04	296.20	569.20	1.35	0.46	581.70	12.00	15.00	16.00	16.00	15.67	5.00	14.00	8.00	NA
P04	N16	8.24E+04	296.30	569.30	0.30	0.10	595.00	6.00	22.00	22.00	NA	22.00	5.00	15.00	7.00	NA
P04	N16	8.24E+04	296.30	569.30	0.30	0.10	595.00	12.00	21.00	22.00	NA	21.50	6.00	12.00	8.00	NA
P04	N16	8.24E+04	296.30	569.30	0.30	0.10	595.00	3.00	23.00	23.00	NA	23.00	6.00	13.00	9.00	NA
P04	N16	8.24E+04	296.30	569.30	0.30	0.10	595.00	9.00	22.00	24.00	NA	23.00	5.00	12.00	9.00	NA
P04	N16	8.24E+04	296.30	569.30	0.30	0.10	605.60	12.00	26.00	27.00	NA	26.50	5.00	12.00	8.00	15.00
P04	N16	8.24E+04	296.30	569.30	0.30	0.10	605.60	6.00	26.00	25.00	NA	25.50	6.00	15.00	9.00	22.00
P04	N16	8.24E+04	296.30	569.30	0.30	0.10	605.60	3.00	28.00	27.00	NA	27.50	6.00	15.00	8.00	19.00

86-151

170877 RD

APPENDIX 1: DATA BASE FOR Zr-2.5 wt% Nb PRESSURE TUBES

P04 N16 8.24E+04	296.30	569.30	0.30	0.10	605.60	9.00	26.00	25.00	NA	25.50	6.00	15.00	9.00	NA
P04 N16 8.24E+04	296.30	569.30	0.00	0.00	609.00	5.00	36.00	36.00	NA	36.00	NA	NA	NA	NA
P04 N16 8.24E+04	296.30	569.30	0.00	0.00	609.00	12.00	37.00	37.00	NA	37.00	NA	NA	NA	NA
P04 N16 8.24E+04	296.30	569.30	0.00	0.00	618.60	12.00	50.00	49.00	NA	49.50	NA	NA	NA	NA
P04 N16 8.24E+04	296.30	569.30	0.00	0.00	618.60	5.00	48.00	48.00	NA	48.00	NA	NA	NA	NA
P04 N16 8.24E+04	296.30	569.30	0.00	0.00	623.50	12.00	61.00	60.00	NA	60.50	NA	NA	NA	NA
P04 N16 8.24E+04	296.30	569.30	0.00	0.00	623.50	5.00	59.00	57.00	NA	58.00	NA	NA	NA	NA
P04 N16 8.24E+04	296.30	569.30	0.00	0.00	625.60	12.00	68.00	69.00	NA	68.50	4.00	14.00	6.00	NA
P04 N16 8.24E+04	296.30	569.30	0.00	0.00	625.60	5.00	71.00	68.00	NA	69.50	6.00	8.00	7.00	NA
P04 N16 8.24E+04	296.30	569.30	0.00	0.00	627.60	5.00	75.00	72.00	NA	73.50	NA	NA	NA	NA
P04 N16 8.24E+04	296.30	569.30	0.00	0.00	627.60	12.00	76.00	74.00	NA	75.00	NA	NA	NA	NA
P04 N16 8.24E+04	296.30	569.30	0.00	0.00	629.20	12.00	78.00	78.00	NA	78.00	2.00	6.00	4.00	NA
P04 N16 8.24E+04	296.30	569.30	0.00	0.00	629.20	5.00	76.00	77.00	NA	76.50	8.00	10.00	8.00	NA
P04 N16 8.24E+04	296.30	569.30	0.00	0.00	630.90	6.00	68.00	67.00	NA	67.50	6.00	10.00	8.00	NA
P04 N16 8.24E+04	296.30	569.30	0.00	0.00	630.90	12.00	85.00	84.00	NA	84.50	2.00	8.00	5.00	NA
P04 N16 8.24E+04	296.30	569.30	0.00	0.00	630.90	5.00	80.00	83.00	NA	81.50	NA	NA	NA	NA
P04 N16 8.24E+04	296.30	569.30	0.00	0.00	632.80	9.00	76.00	73.00	0.00	49.67	NA	NA	NA	NA
P04 N16 8.24E+04	296.30	569.30	0.00	0.00	632.80	3.00	78.00	79.00	NA	78.50	NA	NA	NA	NA
P04 N16 8.24E+04	296.30	569.30	0.00	0.00	632.80	5.00	88.00	91.00	NA	89.50	NA	NA	NA	NA
P04 N16 8.24E+04	296.30	569.30	0.00	0.00	632.80	6.00	68.00	67.00	NA	67.50	6.00	10.00	8.00	NA
P04 N16 8.24E+04	296.30	569.30	0.00	0.00	632.80	12.00	90.00	89.00	NA	89.50	6.00	14.00	9.00	NA
P04 R06 1.51E+04	NA	NA	NA	NA	0.00	NA	NA	NA	NA	NA	1.00	3.00	NA	NA
P04 R06 1.51E+04	NA	NA	NA	NA	7.00	NA	NA	NA	NA	NA	1.00	3.00	NA	NA
P04 R06 1.51E+04	NA	NA	NA	NA	25.00	NA	NA	NA	NA	NA	1.00	2.00	NA	NA
P04 R06 1.51E+04	NA	NA	NA	NA	150.00	NA	NA	NA	NA	NA	1.00	5.00	NA	NA
P04 R06 1.51E+04	NA	NA	NA	NA	353.00	NA	NA	NA	NA	NA	1.00	4.00	NA	NA

APPENDIX 2: DATA BASE FOR ZIRCALOY-2 PRESSURE TUBES

STN/CHL	EFPH	TEMP(C)	TEMP(K)	FLUX ($\times 10^{13}$n/cm^2-sec)	DIS(cm)	CLOCK	D1(PPM)	D2(PPM)	D3(PPM)	DAV(PPM)	MIN_OX (μm)	MAX_OX (μm)	AVG_OX (μm)	PATCH_OX (μm)
NPD G07	1.34E+05	NA	NA	0.00	0.80	6.00	120.00	122.00	116.00	119.33	2.00	6.00	4.00	18.00
NPD G07	1.34E+05	NA	NA	0.00	2.80	6.00	99.00	95.00	101.00	98.33	2.00	4.00	3.00	NA
NPD G07	1.34E+05	NA	NA	0.00	4.80	6.00	68.00	76.00	71.00	71.67	5.00	6.00	5.00	NA
NPD G07	1.34E+05	NA	NA	0.00	6.80	6.00	67.00	68.00	65.00	66.67	2.00	6.00	5.00	12.00
NPD G07	1.34E+05	252.00	525.00	0.05	7.80	9.00	48.00	45.00	43.00	45.33	1.00	4.00	3.00	6.00
NPD G07	1.34E+05	252.00	525.00	0.05	7.80	3.00	49.00	45.00	43.00	45.67	2.00	4.00	3.00	6.00
NPD G07	1.34E+05	252.00	525.00	0.05	7.80	12.00	48.00	50.00	NA	49.00	2.00	4.00	3.00	8.00
NPD G07	1.34E+05	252.00	525.00	0.05	7.80	6.00	46.00	42.00	43.00	43.67	2.00	4.00	3.00	8.00
NPD G07	1.34E+05	254.00	527.00	0.46	71.90	3.00	46.00	41.00	42.00	43.00	20.00	25.00	22.00	32.00
NPD G07	1.34E+05	254.00	527.00	0.46	71.90	9.00	61.00	55.00	54.00	56.67	30.00	40.00	35.00	48.00
NPD G07	1.34E+05	254.00	527.00	0.46	71.90	6.00	56.00	53.00	57.00	55.33	20.00	35.00	30.00	44.00
NPD G07	1.34E+05	254.00	527.00	0.46	71.90	12.00	43.00	44.00	42.00	43.00	20.00	40.00	35.00	52.00
NPD G07	1.34E+05	258.70	531.70	1.01	143.40	12.00	221.00	219.00	224.00	221.33	16.00	20.00	18.00	NA
NPD G07	1.34E+05	258.70	531.70	1.01	143.40	3.00	223.00	207.00	219.00	216.33	8.00	12.00	10.00	NA
NPD G07	1.34E+05	258.70	531.70	1.01	143.40	6.00	211.00	206.00	201.00	206.00	8.00	16.00	12.00	NA
NPD G07	1.34E+05	258.70	531.70	1.01	143.40	9.00	193.00	181.00	187.00	187.00	10.00	16.00	13.00	NA
NPD G07	1.34E+05	266.70	539.70	0.92	236.10	3.00	156.00	160.00	160.00	158.67	14.00	62.00	50.00	NA
NPD G07	1.34E+05	266.70	539.70	0.92	236.10	9.00	198.00	197.00	194.00	196.33	20.00	66.00	50.00	NA
NPD G07	1.34E+05	266.70	539.70	0.92	236.10	6.00	202.00	176.00	200.00	192.67	12.00	64.00	45.00	NA
NPD G07	1.34E+05	266.70	539.70	0.92	236.10	12.00	148.00	141.00	140.00	143.00	14.00	56.00	50.00	NA
NPD G07	1.34E+05	270.00	543.00	0.86	271.90	12.00	168.00	155.00	157.00	160.00	30.00	40.00	35.00	50.00
NPD G07	1.34E+05	270.00	543.00	0.86	271.90	3.00	150.00	160.00	146.00	152.00	30.00	40.00	35.00	52.00
NPD G07	1.34E+05	270.00	543.00	0.86	271.90	9.00	213.00	210.00	196.00	207.00	30.00	40.00	35.00	54.00
NPD G07	1.34E+05	270.00	543.00	0.86	271.90	6.00	216.00	221.00	221.00	219.33	25.00	40.00	35.00	56.00
NPD G07	1.34E+05	274.80	547.80	0.67	341.10	12.00	305.00	270.00	280.00	285.00	18.00	40.00	29.00	NA
NPD G07	1.34E+05	274.80	547.80	0.67	341.10	9.00	290.00	269.00	271.00	276.67	32.00	48.00	40.00	NA
NPD G07	1.34E+05	274.80	547.80	0.67	341.10	6.00	223.00	217.00	221.00	220.33	36.00	48.00	42.00	NA
NPD G07	1.34E+05	274.80	547.80	0.67	341.10	3.00	235.00	227.00	235.00	232.33	14.00	44.00	34.00	NA
NPD G07	1.34E+05	277.00	550.00	0.08	410.10	12.00	121.00	106.00	97.00	108.00	18.00	64.00	50.00	NA
NPD G07	1.34E+05	277.00	550.00	0.08	410.10	6.00	91.00	90.00	87.00	89.33	30.00	50.00	40.00	68.00
NPD G07	1.34E+05	277.00	550.00	0.08	410.10	3.00	97.00	97.00	92.00	95.33	46.00	50.00	35.00	70.00
NPD G07	1.34E+05	277.00	550.00	0.08	410.10	9.00	106.00	93.00	96.00	98.33	40.00	50.00	45.00	60.00
NPD G07	1.34E+05	NA	NA	0.00	412.00	12.00	99.00	104.00	98.00	100.33	4.00	12.00	8.00	NA
NPD G07	1.34E+05	NA	NA	0.00	414.00	3.00	107.00	108.00	102.00	105.67	2.00	8.00	6.00	NA
NPD G07	1.34E+05	NA	NA	0.00	416.00	6.00	114.00	108.00	106.00	109.33	10.00	12.00	11.00	NA
NPD G07	1.34E+05	NA	NA	0.00	417.00	9.00	113.00	130.00	125.00	122.67	10.00	12.00	8.00	NA
PD1 G14	8.90E+04	285.60	558.60	2.13	404.40	9.00	51.00	49.00	48.00	49.33	6.00	8.00	7.00	NA
PD1 G14	8.90E+04	285.60	558.60	2.13	404.40	12.00	48.00	45.00	47.00	46.67	4.00	8.00	6.00	NA
PD1 G14	8.90E+04	285.60	558.60	2.13	404.40	6.00	51.00	48.00	50.00	49.67	20.00	40.00	30.00	NA
PD1 G14	8.90E+04	285.60	558.60	2.13	404.40	3.00	51.00	47.00	48.00	48.67	20.00	40.00	30.00	NA
PD1 G14	8.90E+04	291.30	564.30	1.95	467.20	9.00	81.00	79.00	79.00	79.67	15.00	30.00	23.00	NA
PD1 G14	8.90E+04	291.30	564.30	1.95	467.20	6.00	76.00	76.00	73.00	75.00	30.00	52.00	40.00	NA
PD1 G14	8.90E+04	291.30	564.30	1.95	467.20	3.00	80.00	81.00	80.00	80.33	12.00	36.00	20.00	NA
PD1 G14	8.90E+04	291.30	564.30	1.95	467.20	12.00	86.00	84.00	85.00	85.00	6.00	8.00	7.00	NA
PD1 G16	8.90E+04	248.90	521.90	0.00	1.00	6.00	73.00	72.00	74.00	73.00	1.00	2.00	2.00	NA
PD1 G16	8.90E+04	248.90	521.90	0.00	2.60	6.00	79.00	69.00	78.00	75.33	1.00	2.00	2.00	NA
PD1 G16	8.90E+04	248.90	521.90	0.00	4.30	6.00	64.00	62.00	68.00	64.67	1.00	2.00	2.00	NA
PD1 G16	8.90E+04	248.90	521.90	0.00	6.00	6.00	61.00	65.00	61.00	62.33	1.00	2.00	2.00	NA
PD1 G16	8.90E+04	249.20	522.20	0.30	15.50	6.00	22.00	24.00	24.00	23.33	1.00	2.00	2.00	NA
PD1 G16	8.90E+04	249.50	522.50	0.72	37.00	3.00	25.00	NA	NA	25.00	4.00	6.00	5.00	NA
PD1 G16	8.90E+04	249.50	522.50	0.72	37.00	12.00	33.00	NA	NA	33.00	4.00	6.00	5.00	NA
PD1 G16	8.90E+04	249.50	522.50	0.72	37.00	6.00	26.00	NA	NA	26.00	4.00	6.00	6.00	34.00
PD1 G16	8.90E+04	249.50	522.50	0.72	37.00	9.00	31.00	NA	NA	31.00	4.00	6.00	5.00	NA
PD1 G16	8.90E+04	249.50	522.50	0.72	37.00	9.00	108.00	NA	NA	108.00	4.00	6.00	5.00	NA
PD1 G16	8.90E+04	256.00	529.00	2.06	150.90	9.00	108.00	NA	NA	119.00	4.00	6.00	5.00	NA
PD1 G16	8.90E+04	256.00	529.00	2.06	150.90	3.00	119.00	NA	NA	119.00	4.00	6.00	5.00	18.00
PD1 G16	8.90E+04	256.00	529.00	2.06	150.90	6.00	119.00	NA	NA	110.00	4.00	6.00	5.00	NA
PD1 G16	8.90E+04	256.00	529.00	2.06	150.90	12.00	110.00	NA	NA	67.00	3.00	5.00	4.00	NA
PD1 G16	8.90E+04	270.00	543.00	2.22	274.20	12.00	67.00	NA	NA	66.00	2.00	5.00	4.00	12.00
PD1 G16	8.90E+04	270.00	543.00	2.22	274.20	6.00	66.00	NA	NA	63.00	4.00	6.00	5.00	NA
PD1 G16	8.90E+04	270.00	543.00	2.22	274.20	3.00	63.00	NA	NA	69.00	4.00	6.00	5.00	10.00
PD1 G16	8.90E+04	270.00	543.00	2.22	274.20	9.00	69.00	NA	NA	53.50	6.00	11.00	8.00	NA
PD1 G16	8.90E+04	279.20	552.20	2.20	346.80	9.00	51.00	56.00	NA	56.00	4.00	10.00	6.00	NA
PD1 G16	8.90E+04	279.20	552.20	2.20	346.80	12.00	57.00	55.00	NA	58.50	8.00	20.00	16.00	34.00
PD1 G16	8.90E+04	279.20	552.20	2.20	346.80	6.00	57.00	60.00	NA	56.50	6.00	16.00	14.00	34.00
PD1 G16	8.90E+04	279.20	552.20	2.20	346.80	3.00	57.00	56.00	NA	54.00	14.00	24.00	16.00	34.00
PD1 G16	8.90E+04	284.60	557.60	2.15	395.60	3.00	54.00	NA	NA	64.00	10.00	24.00	14.00	NA
PD1 G16	8.90E+04	284.60	557.60	2.15	395.60	9.00	64.00	NA	NA	72.00	20.00	40.00	30.00	NA
PD1 G16	8.90E+04	284.60	557.60	2.15	395.60	6.00	72.00	NA	NA					

NA = NOT AVAILABLE

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170879 E

APPENDIX 2: DATA BASE FOR ZIRCALOY-2 PRESSURE TUBES

P01	G16	8.90E+04	284.60	557.60	2.15	395.60	12.00	72.00	NA	NA	72.00	4.00	8.00	6.00	NA
P01	G16	8.90E+04	289.30	562.30	2.04	445.90	9.00	91.00	NA	NA	91.00	10.00	16.00	12.00	24.00
P01	G16	8.90E+04	289.30	562.30	2.04	445.90	3.00	99.00	NA	NA	99.00	24.00	40.00	30.00	NA
P01	G16	8.90E+04	289.30	562.30	2.04	445.90	6.00	107.00	NA	NA	107.00	26.00	46.00	34.00	NA
P01	G16	8.90E+04	289.30	562.30	2.04	445.90	12.00	86.00	NA	NA	86.00	4.00	8.00	6.00	12.00
P01	G16	8.90E+04	292.80	565.80	1.79	497.30	3.00	157.00	NA	NA	157.00	20.00	34.00	30.00	NA
P01	G16	8.90E+04	292.80	565.80	1.79	497.30	6.00	141.00	NA	NA	141.00	36.00	52.00	40.00	NA
P01	G16	8.90E+04	292.80	565.80	1.79	497.30	9.00	145.00	NA	NA	145.00	24.00	40.00	32.00	NA
P01	G16	8.90E+04	292.80	565.80	1.79	497.30	12.00	167.00	NA	NA	167.00	4.00	8.00	5.00	12.00
P01	G16	8.90E+04	295.30	568.30	1.30	544.80	12.00	177.00	176.00	NA	176.50	4.00	8.00	5.00	14.00
P01	G16	8.90E+04	295.30	568.30	1.30	544.80	9.00	188.00	187.00	NA	187.50	30.00	42.00	34.00	NA
P01	G16	8.90E+04	295.30	568.30	1.30	544.80	6.00	188.00	186.00	NA	187.00	38.00	50.00	40.00	NA
P01	G16	8.90E+04	295.30	568.30	1.30	544.80	3.00	177.00	186.00	NA	181.50	20.00	36.00	24.00	NA
P01	G16	8.90E+04	295.90	568.90	0.80	569.90	12.00	197.00	NA	NA	197.00	6.00	14.00	10.00	30.00
P01	G16	8.90E+04	295.90	568.90	0.80	569.90	9.00	199.00	NA	NA	199.00	30.00	40.00	36.00	NA
P01	G16	8.90E+04	295.90	568.90	0.80	569.90	6.00	184.00	NA	NA	184.00	36.00	44.00	40.00	NA
P01	G16	8.90E+04	295.90	568.90	0.80	569.90	3.00	208.00	NA	NA	208.00	18.00	32.00	24.00	NA
P01	G16	8.90E+04	296.20	569.20	0.10	598.00	6.00	113.00	NA	NA	113.00	22.00	30.00	26.00	NA
P01	G16	8.90E+04	296.20	569.20	0.10	598.00	12.00	144.00	135.00	NA	139.50	16.00	24.00	20.00	NA
P01	G16	8.90E+04	296.20	569.20	0.10	598.00	3.00	134.00	136.00	NA	135.00	26.00	34.00	30.00	NA
P01	G16	8.90E+04	296.20	569.20	0.10	598.00	9.00	128.00	127.00	NA	127.50	18.00	32.00	26.00	NA
P01	G16	8.90E+04	296.30	569.30	0.00	611.30	6.00	96.00	NA	NA	96.00	16.00	26.00	22.00	NA
P01	G16	8.90E+04	296.30	569.30	0.00	611.30	3.00	100.00	NA	NA	100.00	20.00	40.00	22.00	NA
P01	G16	8.90E+04	296.30	569.30	0.00	611.30	9.00	92.00	NA	NA	92.00	20.00	22.00	21.00	NA
P01	G16	8.90E+04	296.30	569.30	0.00	611.30	12.00	101.00	NA	NA	101.00	10.00	16.00	13.00	NA
P01	G16	8.90E+04	296.30	569.30	0.00	621.90	3.00	79.00	NA	NA	79.00	10.00	12.00	11.00	NA
P01	G16	8.90E+04	296.30	569.30	0.00	621.90	12.00	83.00	NA	NA	83.00	8.00	10.00	9.00	NA
P01	G16	8.90E+04	296.30	569.30	0.00	621.90	6.00	79.00	NA	NA	79.00	10.00	20.00	15.00	NA
P01	G16	8.90E+04	296.30	569.30	0.00	621.90	9.00	81.00	NA	NA	81.00	10.00	16.00	13.00	NA
P01	G16	8.90E+04	296.30	569.30	0.00	625.20	5.00	76.00	75.00	75.00	75.33	1.00	2.00	2.00	NA
P01	G16	8.90E+04	296.30	569.30	0.00	629.20	5.00	90.00	96.00	88.00	91.33	1.00	2.00	2.00	NA
P01	G16	8.90E+04	296.30	569.30	0.00	630.90	5.00	95.00	93.00	89.00	92.33	1.00	2.00	2.00	NA
P01	G16	8.90E+04	296.30	569.30	0.00	632.60	5.00	92.00	87.00	89.00	89.33	1.00	2.00	2.00	NA
P01	G16	8.90E+04	296.30	569.30	0.00	634.00	5.00	94.00	87.00	95.00	92.00	1.00	2.00	2.00	NA
P01	G20	8.90E+04	249.60	522.60	0.72	37.20	3.00	14.00	NA	NA	14.00	NA	NA	NA	NA
P01	G20	8.90E+04	249.60	522.60	0.72	37.20	6.00	13.00	NA	NA	13.00	4.00	8.00	6.00	26.00
P01	G20	8.90E+04	249.60	522.60	0.72	37.20	12.00	13.00	NA	NA	13.00	3.00	6.00	5.00	10.00
P01	G20	8.90E+04	249.60	522.60	0.72	37.20	9.00	11.00	NA	NA	11.00	NA	NA	NA	NA
P01	G20	8.90E+04	256.00	529.00	2.02	150.70	6.00	35.00	NA	NA	35.00	2.00	6.00	4.00	10.00
P01	G20	8.90E+04	256.00	529.00	2.02	150.70	12.00	37.00	NA	NA	37.00	2.00	6.00	4.00	NA
P01	G20	8.90E+04	256.00	529.00	2.02	150.70	9.00	35.00	NA	NA	35.00	NA	NA	NA	NA
P01	G20	8.90E+04	256.00	529.00	2.02	150.70	3.00	35.00	NA	NA	35.00	NA	NA	NA	NA
P01	G20	8.90E+04	270.20	543.20	2.22	274.60	9.00	55.00	NA	NA	55.00	NA	NA	NA	NA
P01	G20	8.90E+04	270.20	543.20	2.22	274.60	3.00	48.00	NA	NA	48.00	NA	NA	NA	NA
P01	G20	8.90E+04	270.20	543.20	2.22	274.60	12.00	53.00	NA	NA	53.00	3.00	7.00	5.00	NA
P01	G20	8.90E+04	270.20	543.20	2.22	274.60	6.00	48.00	NA	NA	48.00	3.00	6.00	5.00	16.00
P01	G20	8.90E+04	279.00	552.00	2.22	344.90	6.00	50.00	NA	NA	50.00	4.00	12.00	6.00	20.00
P01	G20	8.90E+04	279.00	552.00	2.22	344.90	3.00	53.00	NA	NA	53.00	3.00	7.00	5.00	36.00
P01	G20	8.90E+04	279.00	552.00	2.22	344.90	12.00	53.00	NA	NA	53.00	4.00	8.00	6.00	NA
P01	G20	8.90E+04	279.00	552.00	2.22	344.90	9.00	52.00	NA	NA	52.00	3.00	7.00	5.00	NA
P01	G20	8.90E+04	285.20	558.20	2.14	401.50	9.00	51.00	NA	NA	51.00	4.00	7.00	6.00	14.00
P01	G20	8.90E+04	285.20	558.20	2.14	401.50	12.00	42.00	NA	NA	42.00	4.00	8.00	6.00	NA
P01	G20	8.90E+04	285.20	558.20	2.14	401.50	6.00	58.00	NA	NA	58.00	14.00	30.00	20.00	NA
P01	G20	8.90E+04	285.20	558.20	2.14	401.50	3.00	49.00	NA	NA	49.00	4.00	7.00	6.00	14.00
P01	G20	8.90E+04	289.70	562.70	2.03	447.90	6.00	64.00	NA	NA	64.00	18.00	32.00	22.00	NA
P01	G20	8.90E+04	289.70	562.70	2.03	447.90	3.00	58.00	NA	NA	58.00	8.00	12.00	10.00	24.00
P01	G20	8.90E+04	289.70	562.70	2.03	447.90	9.00	60.00	NA	NA	60.00	2.00	6.00	5.00	14.00
P01	G20	8.90E+04	289.70	562.70	2.03	447.90	12.00	50.00	NA	NA	50.00	4.00	8.00	6.00	16.00
P01	G20	8.90E+04	293.20	566.20	1.79	497.50	3.00	79.00	NA	NA	79.00	16.00	34.00	24.00	NA
P01	G20	8.90E+04	293.20	566.20	1.79	497.50	9.00	86.00	NA	NA	86.00	5.00	14.00	10.00	22.00
P01	G20	8.90E+04	293.20	566.20	1.79	497.50	12.00	71.00	NA	NA	71.00	4.00	7.00	5.00	18.00
P01	G20	8.90E+04	293.20	566.20	1.79	497.50	6.00	83.00	NA	NA	83.00	22.00	34.00	30.00	NA
P01	G20	8.90E+04	295.50	568.50	1.30	546.70	12.00	77.00	NA	NA	77.00	14.00	24.00	18.00	NA
P01	G20	8.90E+04	295.50	568.50	1.30	546.70	9.00	81.00	NA	NA	81.00	12.00	24.00	26.00	NA
P01	G20	8.90E+04	295.50	568.50	1.30	546.70	3.00	81.00	NA	NA	81.00	20.00	30.00	24.00	NA
P01	G20	8.90E+04	295.50	568.50	1.30	546.70	6.00	81.00	NA	NA	81.00	14.00	34.00	30.00	NA
P01	G20	8.90E+04	296.30	569.30	0.20	596.70	3.00	79.00	NA	NA	79.00	14.00	22.00	18.00	NA
P01	G20	8.90E+04	296.30	569.30	0.20	596.70	12.00	80.00	NA	NA	80.00	10.00	14.00	12.00	NA
P01	G20	8.90E+04	296.30	569.30	0.20	596.70	6.00	79.00	NA	NA	79.00	10.00	14.00	12.00	NA
P01	G20	8.90E+04	296.30	569.30	0.20	596.70	9.00	82.00	NA	NA	82.00	16.00	24.00	18.00	NA
P01	G20	8.90E+04	296.30	569.30	0.00	619.90	9.00	73.00	NA	NA	73.00	2.00	12.00	10.00	NA
P01	G20	8.90E+04	296.30	569.30	0.00	619.90	12.00	70.00	NA	NA	70.00	10.00	14.00	12.00	NA
P01	G20	8.90E+04	296.30	569.30	0.00	619.90	6.00	77.00	NA	NA	77.00	6.00	8.00	7.00	NA

APPENDIX 2: DATA BASE FOR ZIRCALOY-2 PRESSURE TUBES

P01	G20	8.90E+04	296.30	569.30	0.00	619.90	3.00	75.00	NA	NA	75.00	6.00	8.00	7.00	NA
P01	K05	8.90E+04	250.00	523.00	1.00	52.40	12.00	21.00	21.00	18.00	20.00	4.00	6.00	5.00	8.00
P01	K05	8.90E+04	250.00	523.00	1.00	52.40	9.00	24.00	21.00	22.00	22.33	4.00	7.00	5.00	NA
P01	K05	8.90E+04	250.00	523.00	1.00	52.40	6.00	25.00	21.00	22.00	22.67	5.00	7.00	6.00	32.00
P01	K05	8.90E+04	250.00	523.00	1.00	52.40	3.00	23.00	19.00	20.00	20.67	4.00	7.00	5.00	9.00
P01	K05	8.90E+04	252.20	525.20	1.64	98.00	6.00	59.00	58.00	60.00	59.00	4.00	6.00	5.00	10.00
P01	K05	8.90E+04	252.20	525.20	1.64	98.00	12.00	66.00	66.00	66.00	66.00	4.00	6.00	4.00	NA
P01	K05	8.90E+04	252.20	525.20	1.64	98.00	3.00	61.00	60.00	62.00	61.00	3.00	6.00	4.00	NA
P01	K05	8.90E+04	252.20	525.20	1.64	98.00	9.00	73.00	71.00	70.00	71.33	2.00	6.00	4.00	NA
P01	K05	8.90E+04	256.20	529.20	2.04	151.90	6.00	61.00	60.00	63.00	61.33	4.00	10.00	6.00	40.00
P01	K05	8.90E+04	256.20	529.20	2.04	151.90	3.00	70.00	71.00	80.00	73.67	4.00	6.00	5.00	NA
P01	K05	8.90E+04	256.20	529.20	2.04	151.90	9.00	71.00	72.00	73.00	72.00	4.00	8.00	6.00	NA
P01	K05	8.90E+04	256.20	529.20	2.04	151.90	12.00	77.00	76.00	74.00	75.67	4.00	8.00	6.00	NA
P01	K05	8.90E+04	261.50	534.50	2.15	200.00	6.00	61.00	54.00	69.00	61.33	4.00	6.00	5.00	10.00
P01	K05	8.90E+04	261.50	534.50	2.15	200.00	12.00	65.00	63.00	62.00	63.33	3.00	6.00	4.00	NA
P01	K05	8.90E+04	261.50	534.50	2.15	200.00	9.00	70.00	69.00	64.00	67.67	3.00	6.00	4.00	14.00
P01	K05	8.90E+04	261.50	534.50	2.15	200.00	3.00	62.00	62.00	66.00	63.33	4.00	6.00	5.00	9.00
P01	K05	8.90E+04	270.30	543.30	2.22	274.90	12.00	45.00	46.00	46.00	45.67	4.00	8.00	6.00	NA
P01	K05	8.90E+04	270.30	543.30	2.22	274.90	9.00	43.00	44.00	43.00	43.33	4.00	8.00	6.00	16.00
P01	K05	8.90E+04	270.30	543.30	2.22	274.90	6.00	46.00	45.00	44.00	45.00	4.00	10.00	6.00	NA
P01	K05	8.90E+04	270.30	543.30	2.22	274.90	3.00	44.00	47.00	45.00	45.33	4.00	8.00	6.00	28.00
P01	K05	8.90E+04	279.60	552.60	2.20	351.20	9.00	79.00	82.00	78.00	79.67	10.00	20.00	14.00	NA
P01	K05	8.90E+04	279.60	552.60	2.20	351.20	12.00	57.00	57.00	57.00	57.00	6.00	10.00	7.00	16.00
P01	K05	8.90E+04	279.60	552.60	2.20	351.20	3.00	69.00	70.00	NA	69.50	6.00	10.00	8.00	24.00
P01	K05	8.90E+04	279.60	552.60	2.20	351.20	6.00	84.00	88.00	91.00	87.67	15.00	33.00	17.00	NA
P01	K05	8.90E+04	285.30	558.30	2.14	402.20	12.00	82.00	84.00	81.00	82.33	5.00	7.00	6.00	14.00
P01	K05	8.90E+04	285.30	558.30	2.14	402.20	3.00	108.00	108.00	100.00	105.33	12.00	22.00	16.00	30.00
P01	K05	8.90E+04	285.30	558.30	2.14	402.20	9.00	96.00	100.00	98.00	98.00	8.00	14.00	10.00	26.00
P01	K05	8.90E+04	285.30	558.30	2.14	402.20	6.00	120.00	128.00	126.00	124.67	20.00	28.00	24.00	58.00
P01	K05	8.90E+04	289.80	562.80	2.04	446.20	12.00	109.00	101.00	107.00	105.67	6.00	10.00	7.00	NA
P01	K05	8.90E+04	289.80	562.80	2.04	446.20	3.00	107.00	106.00	104.00	105.67	12.00	24.00	18.00	30.00
P01	K05	8.90E+04	289.80	562.80	2.04	446.20	6.00	103.00	105.00	104.00	104.00	20.00	38.00	25.00	NA
P01	K05	8.90E+04	289.80	562.80	2.04	446.20	9.00	106.00	115.00	114.00	111.67	8.00	16.00	12.00	24.00
P01	K05	8.90E+04	293.50	566.50	1.76	500.20	6.00	159.00	135.00	163.00	152.33	24.00	40.00	30.00	NA
P01	K05	8.90E+04	293.50	566.50	1.76	500.20	12.00	128.00	126.00	124.00	126.00	6.00	10.00	8.00	16.00
P01	K05	8.90E+04	293.50	566.50	1.76	500.20	9.00	150.00	147.00	139.00	145.33	10.00	16.00	14.00	26.00
P01	K05	8.90E+04	293.50	566.50	1.76	500.20	3.00	163.00	157.00	135.00	151.67	24.00	34.00	30.00	56.00
P01	K05	8.90E+04	295.50	568.50	1.22	549.20	12.00	144.00	142.00	146.00	144.00	10.00	16.00	14.00	26.00
P01	K05	8.90E+04	295.50	568.50	1.22	549.20	3.00	126.00	141.00	125.00	130.67	22.00	36.00	30.00	NA
P01	K05	8.90E+04	295.50	568.50	1.22	549.20	9.00	177.00	169.00	176.00	174.00	8.00	18.00	16.00	26.00
P01	K05	8.90E+04	295.50	568.50	1.22	549.20	6.00	154.00	162.00	152.00	156.00	24.00	34.00	30.00	NA
P01	K05	8.90E+04	296.20	569.20	0.54	582.60	6.00	166.00	184.00	173.00	174.33	20.00	35.00	30.00	NA
P01	K05	8.90E+04	296.20	569.20	0.54	582.60	3.00	196.00	203.00	204.00	201.00	21.00	31.00	27.00	37.00
P01	K05	8.90E+04	296.20	569.20	0.54	582.60	9.00	185.00	180.00	185.00	183.33	20.00	27.00	23.00	NA
P01	K05	8.90E+04	296.20	569.20	0.54	582.60	12.00	198.00	185.00	197.00	193.33	10.00	22.00	15.00	NA
P01	K05	8.90E+04	296.30	569.30	0.20	596.40	12.00	132.00	147.00	131.00	136.67	14.00	20.00	16.00	NA
P01	K05	8.90E+04	296.30	569.30	0.20	596.40	9.00	132.00	132.00	133.00	132.33	20.00	30.00	24.00	NA
P01	K05	8.90E+04	296.30	569.30	0.20	596.40	3.00	117.00	119.00	122.00	119.33	20.00	30.00	24.00	NA
P01	K05	8.90E+04	296.30	569.30	0.20	596.40	6.00	123.00	125.00	118.00	122.00	20.00	36.00	30.00	NA
P01	K05	8.90E+04	296.30	569.30	0.00	617.00	6.00	67.00	69.00	64.00	66.67	14.00	20.00	16.00	NA
P01	K05	8.90E+04	296.30	569.30	0.00	617.00	12.00	78.00	73.00	83.00	78.00	10.00	16.00	12.00	NA
P01	K05	8.90E+04	296.30	569.30	0.00	617.00	3.00	73.00	71.00	67.00	70.33	16.00	30.00	24.00	NA
P01	K05	8.90E+04	296.30	569.30	0.00	617.00	9.00	77.00	70.00	77.00	74.67	10.00	16.00	12.00	NA
P01	K18	8.90E+04	249.60	522.60	0.74	37.20	6.00	25.00	23.00	23.00	23.67	4.00	6.00	5.00	16.00
P01	K18	8.90E+04	249.60	522.60	0.74	37.20	9.00	20.00	20.00	20.00	20.00	3.00	5.00	4.00	NA
P01	K18	8.90E+04	249.60	522.60	0.74	37.20	12.00	50.00	50.00	21.00	40.33	3.00	5.00	4.00	10.00
P01	K18	8.90E+04	249.60	522.60	0.74	37.20	3.00	20.00	20.00	21.00	20.33	4.00	6.00	5.00	10.00
P01	K18	8.90E+04	254.30	527.30	1.94	136.50	9.00	80.00	79.00	82.00	80.33	4.00	6.00	5.00	10.00
P01	K18	8.90E+04	254.30	527.30	1.94	136.50	6.00	67.00	67.00	68.00	67.33	5.00	10.00	6.00	22.00
P01	K18	8.90E+04	254.30	527.30	1.94	136.50	3.00	91.00	96.00	98.00	95.00	3.00	5.00	4.00	8.00
P01	K18	8.90E+04	254.30	527.30	1.94	136.50	12.00	100.00	104.00	NA	102.00	4.00	6.00	5.00	12.00
P01	K18	8.90E+04	255.20	528.20	1.98	140.00	6.00	84.00	85.00	88.00	85.67	6.00	8.00	7.00	NA
P01	K18	8.90E+04	255.20	528.20	1.98	140.00	12.00	114.00	111.00	91.00	105.33	8.00	12.00	10.00	NA
P01	K18	8.90E+04	255.20	528.20	1.98	140.00	9.00	81.00	86.00	88.00	85.00	6.00	10.00	8.00	NA
P01	K18	8.90E+04	255.20	528.20	1.98	140.00	3.00	108.00	108.00	115.00	110.33	6.00	10.00	8.00	NA
P01	K18	8.90E+04	258.40	531.40	2.11	173.50	6.00	50.00	NA	NA	50.00	NA	NA	NA	NA
P01	K18	8.90E+04	258.40	531.40	2.11	173.50	12.00	74.00	NA	NA	74.00	NA	NA	NA	NA
P01	K18	8.90E+04	258.40	531.40	2.11	173.50	9.00	66.00	NA	NA	66.00	NA	NA	NA	NA
P01	K18	8.90E+04	258.40	531.40	2.11	173.50	3.00	80.00	NA	NA	80.00	NA	NA	NA	NA
P01	K18	8.90E+04	260.70	533.70	2.14	194.40	3.00	112.00	109.00	110.00	110.33	4.00	8.00	7.00	NA
P01	K18	8.90E+04	260.70	533.70	2.14	194.40	6.00	77.00	73.00	71.00	73.67	2.00	6.00	5.00	NA
P01	K18	8.90E+04	260.70	533.70	2.14	194.40	9.00	91.00	80.00	75.00	82.00	7.00	10.00	8.00	NA
P01	K18	8.90E+04	260.70	533.70	2.14	194.40	12.00	121.00	131.00	107.00	119.67	2.00	6.00	5.00	NA

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APPENDIX 2: DATA BASE FOR ZIRCALOY-2 PRESSURE TUBES

P01	K18	8.90E+04	261.50	534.50	2.15	198.50	12.00	129.00	129.00	NA	129.00	4.00	8.00	6.00	14.00
P01	K18	8.90E+04	261.50	534.50	2.15	198.50	3.00	93.00	93.00	85.00	90.33	4.00	10.00	6.00	NA
P01	K18	8.90E+04	261.50	534.50	2.15	198.50	6.00	66.00	70.00	67.00	67.67	4.00	10.00	6.00	16.00
P01	K18	8.90E+04	261.50	534.50	2.15	198.50	9.00	88.00	83.00	83.00	84.67	4.00	8.00	6.00	14.00
P01	K18	8.90E+04	272.20	545.20	2.22	287.80	6.00	75.00	69.00	61.00	68.33	10.00	30.00	20.00	NA
P01	K18	8.90E+04	272.20	545.20	2.22	287.80	9.00	56.00	57.00	43.00	52.00	6.00	12.00	10.00	NA
P01	K18	8.90E+04	272.20	545.20	2.22	287.80	3.00	59.00	61.00	63.00	61.00	10.00	20.00	15.00	NA
P01	K18	8.90E+04	272.20	545.20	2.22	287.80	12.00	54.00	70.00	66.00	63.33	6.00	10.00	8.00	NA
P01	K18	8.90E+04	279.60	552.60	2.20	350.50	9.00	87.00	96.00	86.00	89.67	20.00	40.00	30.00	NA
P01	K18	8.90E+04	279.60	552.60	2.20	350.50	6.00	85.00	85.00	76.00	82.00	15.00	40.00	30.00	NA
P01	K18	8.90E+04	279.60	552.60	2.20	350.50	12.00	52.00	53.00	52.00	52.33	8.00	20.00	15.00	NA
P01	K18	8.90E+04	279.60	552.60	2.20	350.50	3.00	58.00	63.00	54.00	58.33	30.00	40.00	35.00	NA
P01	K18	8.90E+04	285.30	558.30	2.13	403.20	3.00	117.00	119.00	119.00	118.33	30.00	50.00	45.00	NA
P01	K18	8.90E+04	285.30	558.30	2.13	403.20	12.00	74.00	80.00	82.00	78.67	10.00	20.00	15.00	NA
P01	K18	8.90E+04	285.30	558.30	2.13	403.20	6.00	164.00	150.00	156.00	156.67	45.00	55.00	50.00	NA
P01	K18	8.90E+04	285.30	558.30	2.13	403.20	9.00	112.00	106.00	115.00	111.00	20.00	40.00	30.00	NA
P01	K18	8.90E+04	290.00	563.00	2.02	452.70	6.00	280.00	285.00	276.00	280.33	50.00	60.00	55.00	NA
P01	K18	8.90E+04	290.00	563.00	2.02	452.70	9.00	199.00	201.00	200.00	200.00	40.00	45.00	42.00	NA
P01	K18	8.90E+04	290.00	563.00	2.02	452.70	12.00	169.00	175.00	186.00	176.67	8.00	30.00	20.00	NA
P01	K18	8.90E+04	290.00	563.00	2.02	452.70	3.00	273.00	254.00	284.00	270.33	30.00	50.00	45.00	NA
P01	K18	8.90E+04	293.50	566.50	1.76	501.30	3.00	388.00	380.00	NA	384.00	40.00	50.00	45.00	NA
P01	K18	8.90E+04	293.50	566.50	1.76	501.30	9.00	313.00	309.00	318.00	313.33	40.00	50.00	45.00	NA
P01	K18	8.90E+04	293.50	566.50	1.76	501.30	6.00	280.00	272.00	283.00	278.33	50.00	60.00	55.00	NA
P01	K18	8.90E+04	293.50	566.50	1.76	501.30	12.00	291.00	290.00	322.00	301.00	10.00	20.00	15.00	NA
P01	K18	8.90E+04	295.50	568.50	1.30	546.80	6.00	178.00	183.00	184.00	181.67	36.00	56.00	50.00	NA
P01	K18	8.90E+04	295.50	568.50	1.30	546.80	3.00	279.00	218.00	189.00	228.67	36.00	50.00	46.00	NA
P01	K18	8.90E+04	295.50	568.50	1.30	546.80	9.00	213.00	220.00	NA	216.50	34.00	54.00	40.00	NA
P01	K18	8.90E+04	295.50	568.50	1.30	546.80	12.00	274.00	280.00	293.00	282.33	24.00	44.00	30.00	NA
P01	K18	8.90E+04	295.70	568.70	1.20	550.80	6.00	175.00	174.00	190.00	179.67	45.00	60.00	55.00	NA
P01	K18	8.90E+04	295.70	568.70	1.20	550.80	9.00	263.00	279.00	NA	271.00	40.00	50.00	45.00	NA
P01	K18	8.90E+04	295.70	568.70	1.20	550.80	12.00	322.00	338.00	NA	330.00	10.00	40.00	25.00	NA
P01	K18	8.90E+04	295.70	568.70	1.20	550.80	3.00	263.00	255.00	270.00	262.67	40.00	55.00	50.00	NA
P01	K18	8.90E+04	296.30	569.30	0.10	597.30	3.00	104.00	104.00	109.00	105.67	25.00	35.00	30.00	NA
P01	K18	8.90E+04	296.30	569.30	0.10	597.30	9.00	106.00	114.00	97.00	105.67	20.00	30.00	25.00	NA
P01	K18	8.90E+04	296.30	569.30	0.10	597.30	6.00	96.00	100.00	100.00	98.67	30.00	40.00	35.00	NA
P01	K18	8.90E+04	296.30	569.30	0.10	597.30	12.00	111.00	105.00	115.00	110.33	18.00	30.00	25.00	NA
P02	G16	8.68E+04	248.90	521.90	0.00	2.00	6.00	NA	NA	NA	NA	1.00	4.00	1.00	6.00
P02	G16	8.68E+04	248.90	521.90	0.00	4.00	6.00	NA	NA	NA	NA	1.00	2.00	1.00	NA
P02	G16	8.68E+04	248.90	521.90	0.00	6.00	6.00	NA	NA	NA	NA	1.00	4.00	2.00	8.00
P02	G16	8.68E+04	249.00	522.00	0.00	8.00	6.00	NA	NA	NA	NA	1.00	2.00	2.00	8.00
P02	G16	8.68E+04	250.00	523.00	1.00	52.00	12.00	61.00	62.00	64.00	62.33	4.00	12.00	6.00	16.00
P02	G16	8.68E+04	250.00	523.00	1.00	52.00	9.00	59.00	63.00	63.00	61.67	4.00	12.00	8.00	16.00
P02	G16	8.68E+04	250.00	523.00	1.00	52.00	6.00	61.00	62.00	62.00	61.67	4.00	12.00	6.00	16.00
P02	G16	8.68E+04	250.00	523.00	1.00	52.00	3.00	60.00	60.00	63.00	61.00	4.00	12.00	6.00	NA
P02	G16	8.68E+04	255.30	528.30	1.90	142.00	3.00	56.00	56.00	57.00	56.33	4.00	10.00	6.00	16.00
P02	G16	8.68E+04	255.30	528.30	1.90	142.00	6.00	54.00	55.00	55.00	54.67	4.00	12.00	6.00	16.00
P02	G16	8.68E+04	255.30	528.30	1.90	142.00	9.00	52.00	53.00	54.00	53.00	4.00	12.00	6.00	16.00
P02	G16	8.68E+04	255.30	528.30	1.90	142.00	12.00	52.00	52.00	53.00	52.33	4.00	12.00	6.00	16.00
P02	G16	8.68E+04	265.30	538.30	2.11	235.00	6.00	31.00	32.00	32.00	31.67	4.00	10.00	6.00	NA
P02	G16	8.68E+04	265.30	538.30	2.11	235.00	12.00	33.00	35.00	35.00	34.33	4.00	10.00	6.00	26.00
P02	G16	8.68E+04	265.30	538.30	2.11	235.00	9.00	34.00	34.00	35.00	34.33	4.00	12.00	6.00	18.00
P02	G16	8.68E+04	265.30	538.30	2.11	235.00	3.00	32.00	33.00	33.00	32.67	4.00	10.00	6.00	16.00
P02	G16	8.68E+04	277.40	550.40	2.14	331.00	3.00	32.00	33.00	39.00	34.67	8.00	36.00	16.00	NA
P02	G16	8.68E+04	277.40	550.40	2.14	331.00	6.00	41.00	42.00	44.00	42.33	NA	38.00	NA	NA
P02	G16	8.68E+04	277.40	550.40	2.14	331.00	9.00	25.00	29.00	29.00	27.67	2.00	14.00	6.00	NA
P02	G16	8.68E+04	277.40	550.40	2.14	331.00	12.00	53.00	57.00	58.00	56.00	6.00	16.00	6.00	NA
P02	G16	8.68E+04	287.10	560.10	2.02	415.00	9.00	75.00	77.00	80.00	77.33	2.00	14.00	10.00	NA
P02	G16	8.68E+04	287.10	560.10	2.02	415.00	5.00	NA	NA	NA	NA	20.00	84.00	40.00	NA
P02	G16	8.68E+04	287.10	560.10	2.02	415.00	3.00	86.00	88.00	88.00	87.33	6.00	35.00	20.00	NA
P02	G16	8.68E+04	287.10	560.10	2.02	415.00	7.00	NA	NA	NA	NA	16.00	42.00	24.00	NA
P02	G16	8.68E+04	287.10	560.10	2.02	415.00	4.00	NA	NA	NA	NA	18.00	68.00	30.00	NA
P02	G16	8.68E+04	287.10	560.10	2.02	415.00	6.00	64.00	95.00	134.00	97.67	10.00	54.00	24.00	NA
P02	G16	8.68E+04	287.10	560.10	2.02	415.00	12.00	57.00	59.00	59.00	58.33	2.00	20.00	6.00	NA
P02	G16	8.68E+04	287.50	560.50	1.99	426.00	4.00	NA	NA	NA	NA	20.00	34.00	24.00	NA
P02	G16	8.68E+04	287.50	560.50	1.99	426.00	6.00	NA	NA	NA	NA	18.00	34.00	24.00	NA
P02	G16	8.68E+04	287.50	560.50	1.99	426.00	7.00	NA	NA	NA	NA	20.00	38.00	30.00	NA
P02	G16	8.68E+04	287.50	560.50	1.99	426.00	5.00	NA	NA	NA	NA	18.00	38.00	24.00	NA
P02	G16	8.68E+04	287.50	560.50	1.99	426.00	8.00	NA	NA	NA	NA	15.00	42.00	30.00	NA
P02	G16	8.68E+04	288.40	561.40	1.97	434.00	6.00	NA	NA	NA	NA	20.00	40.00	30.00	NA
P02	G16	8.68E+04	288.50	561.50	1.96	437.00	7.00	NA	NA	NA	NA	18.00	40.00	30.00	NA
P02	G16	8.68E+04	288.50	561.50	1.96	437.00	6.00	NA	NA	NA	NA	16.00	34.00	24.00	NA
P02	G16	8.68E+04	289.00	562.00	1.95	439.00	6.00	NA	NA	NA	NA	10.00	40.00	30.00	NA
P02	G16	8.68E+04	290.20	563.20	1.90	454.00	6.00	NA	NA	NA	NA	16.00	40.00	30.00	NA

APPENDIX 2: DATA BASE FOR ZIRCALOY-2 PRESSURE TUBES

PQ2	G16	8.68E+04	290.50	563.50	1.88	459.00	7.00	112.00	112.00	119.00	114.33	NA	NA	NA	NA
PQ2	G16	8.68E+04	290.50	563.50	1.88	459.00	10.00	98.00	102.00	103.00	101.00	14.00	36.00	24.00	NA
PQ2	G16	8.68E+04	290.50	563.50	1.88	459.00	8.00	111.00	114.00	114.00	113.00	NA	NA	NA	NA
PQ2	G16	8.68E+04	290.50	563.50	1.88	459.00	10.00	105.00	106.00	109.00	106.67	NA	NA	NA	NA
PQ2	G16	8.68E+04	290.50	563.50	1.88	459.00	7.00	99.00	111.00	126.00	112.00	NA	NA	NA	NA
PQ2	G16	8.68E+04	290.50	563.50	1.88	459.00	0.00	228.00	257.00	NA	242.50	20.00	48.00	30.00	NA
PQ2	G16	8.68E+04	290.50	563.50	1.88	459.00	6.00	155.00	178.00	NA	166.50	18.00	46.00	30.00	NA
PQ2	G16	8.68E+04	290.50	563.50	1.88	459.00	6.00	104.00	108.00	114.00	108.67	NA	NA	NA	NA
PQ2	G16	8.68E+04	290.50	563.50	1.88	459.00	11.00	130.00	130.00	139.00	133.00	8.00	32.00	16.00	NA
PQ2	G16	8.68E+04	290.50	563.50	1.88	459.00	8.00	105.00	106.00	110.00	107.00	NA	NA	NA	NA
PQ2	G16	8.68E+04	290.80	563.80	1.85	465.00	7.00	NA	NA	NA	NA	20.00	46.00	40.00	NA
PQ2	G16	8.68E+04	292.10	565.10	1.82	475.00	12.00	123.00	127.00	130.00	126.67	14.00	36.00	20.00	NA
PQ2	G16	8.68E+04	292.10	565.10	1.82	475.00	6.00	NA	NA	NA	NA	30.00	42.00	36.00	NA
PQ2	G16	8.68E+04	292.10	565.10	1.82	475.00	9.00	103.00	118.00	122.00	114.33	16.00	38.00	24.00	NA
PQ2	G16	8.68E+04	292.10	565.10	1.82	475.00	7.00	NA	NA	NA	NA	34.00	52.00	40.00	NA
PQ2	G16	8.68E+04	292.20	565.20	1.82	476.00	9.00	139.00	141.00	144.00	141.33	NA	NA	NA	NA
PQ2	G16	8.68E+04	292.20	565.20	1.82	476.00	7.00	134.00	143.00	137.00	138.00	NA	NA	NA	NA
PQ2	G16	8.68E+04	292.20	565.20	1.82	476.00	8.00	146.00	151.00	154.00	150.33	16.00	38.00	24.00	NA
PQ2	G16	8.68E+04	292.20	565.20	1.82	476.00	12.00	143.00	144.00	146.00	144.33	16.00	34.00	20.00	NA
PQ2	G16	8.68E+04	292.20	565.20	1.82	476.00	6.00	NA	NA	NA	NA	22.00	46.00	30.00	NA
PQ2	G16	8.68E+04	292.80	565.80	1.68	494.00	6.00	NA	NA	NA	NA	24.00	50.00	34.00	NA
PQ2	G16	8.68E+04	293.90	566.90	1.60	505.00	6.00	172.00	175.00	190.00	179.00	22.00	52.00	40.00	NA
PQ2	G16	8.68E+04	293.90	566.90	1.60	505.00	12.00	160.00	164.00	170.00	164.67	14.00	36.00	24.00	NA
PQ2	G16	8.68E+04	293.90	566.90	1.60	505.00	9.00	169.00	177.00	183.00	176.33	20.00	40.00	30.00	NA
PQ2	G16	8.68E+04	294.80	567.80	1.26	531.00	6.00	227.00	227.00	231.00	228.33	30.00	54.00	40.00	NA
PQ2	G16	8.68E+04	294.80	567.80	1.26	531.00	9.00	262.00	263.00	269.00	264.67	24.00	40.00	30.00	NA
PQ2	G16	8.68E+04	294.80	567.80	1.26	531.00	12.00	325.00	341.00	299.00	321.67	16.00	38.00	30.00	NA
PQ2	G16	8.68E+04	296.10	569.10	0.70	566.00	9.00	289.00	311.00	309.00	303.00	12.00	20.00	NA	NA
PQ2	G16	8.68E+04	296.10	569.10	0.70	566.00	12.00	209.00	217.00	211.00	212.33	18.00	32.00	24.00	NA
PQ2	G16	8.68E+04	296.10	569.10	0.70	566.00	6.00	167.00	170.00	179.00	172.00	20.00	38.00	30.00	NA
PQ2	G16	8.68E+04	296.30	569.30	0.08	596.00	5.00	148.00	154.00	161.00	154.33	NA	NA	NA	NA
PQ2	G16	8.68E+04	296.30	569.30	0.08	596.00	6.00	NA	NA	NA	NA	10.00	44.00	30.00	NA
PQ2	G16	8.68E+04	296.30	569.30	0.00	600.00	5.00	137.00	143.00	152.00	144.00	NA	NA	NA	NA
PQ2	G16	8.68E+04	296.30	569.30	0.00	604.00	5.00	122.00	125.00	137.00	128.00	NA	NA	NA	NA
PQ2	G16	8.68E+04	296.30	569.30	0.00	608.00	5.00	131.00	132.00	135.00	132.67	NA	NA	NA	NA
PQ2	G16	8.68E+04	296.30	569.30	0.00	612.00	5.00	110.00	116.00	120.00	115.33	NA	NA	NA	NA
PQ2	G16	8.68E+04	296.30	569.30	0.00	616.00	5.00	108.00	115.00	121.00	114.67	NA	NA	NA	NA
PQ2	G16	8.68E+04	296.30	569.30	0.00	618.00	12.00	112.00	116.00	125.00	117.67	4.00	12.00	6.00	NA
PQ2	G16	8.68E+04	296.30	569.30	0.00	622.00	6.00	86.00	117.00	127.00	110.67	6.00	20.00	12.00	NA
PQ2	G16	8.68E+04	296.30	569.30	0.00	622.00	9.00	133.00	132.00	135.00	133.33	6.00	16.00	10.00	NA
PQ2	G16	8.68E+04	296.30	569.30	0.00	622.00	12.00	121.00	126.00	135.00	127.33	6.00	16.00	8.00	NA
PQ2	G16	8.68E+04	296.30	569.30	0.00	624.00	11.00	NA	NA	NA	NA	4.00	10.00	6.00	14.00
PQ2	G16	8.68E+04	296.30	569.30	0.00	624.00	5.00	128.00	132.00	133.00	131.00	8.00	12.00	10.00	16.00
PQ2	G16	8.68E+04	296.30	569.30	0.00	625.00	5.00	NA	NA	NA	NA	NA	NA	NA	NA
PQ2	G16	8.68E+04	296.30	569.30	0.00	625.00	7.00	121.00	123.00	125.00	123.00	8.00	14.00	10.00	NA
PQ2	G16	8.68E+04	296.30	569.30	0.00	626.00	12.00	NA	NA	NA	NA	4.00	8.00	6.00	16.00
PQ2	G16	8.68E+04	296.30	569.30	0.00	626.00	5.00	NA	NA	NA	NA	NA	NA	NA	NA
PQ2	G16	8.68E+04	296.30	569.30	0.00	627.00	5.00	NA	NA	NA	NA	8.00	12.00	10.00	16.00
PQ2	G16	8.68E+04	296.30	569.30	0.00	628.00	5.00	123.00	124.00	136.00	127.67	NA	NA	NA	NA
PQ2	G16	8.68E+04	296.30	569.30	0.00	629.00	5.00	NA	NA	NA	NA	NA	NA	NA	NA
PQ2	G16	8.68E+04	296.30	569.30	0.00	629.00	11.00	NA	NA	NA	NA	4.00	10.00	6.00	14.00
PQ2	G16	8.68E+04	296.30	569.30	0.00	630.00	5.00	116.00	123.00	129.00	122.67	8.00	12.00	10.00	16.00
PQ2	J15	8.68E+04	248.90	521.90	0.00	1.00	6.00	NA	NA	NA	NA	NA	NA	NA	NA
PQ2	J15	8.68E+04	248.90	521.90	0.00	2.00	7.00	118.00	114.00	116.00	116.00	NA	NA	NA	NA
PQ2	J15	8.68E+04	248.90	521.90	0.00	3.00	7.00	144.00	139.00	134.00	139.00	NA	NA	NA	NA
PQ2	J15	8.68E+04	248.90	521.90	0.00	4.00	7.00	160.00	166.00	166.00	164.00	NA	NA	NA	NA
PQ2	J15	8.68E+04	248.90	521.90	0.00	6.00	7.00	112.00	126.00	128.00	122.00	NA	NA	NA	NA
PQ2	J15	8.68E+04	248.90	521.90	0.00	8.00	7.00	69.00	64.00	66.00	66.33	NA	NA	NA	NA
PQ2	J15	8.68E+04	248.90	521.90	0.00	9.00	6.00	NA	NA	NA	NA	2.00	6.00	4.00	NA
PQ2	J15	8.68E+04	249.00	522.00	0.12	11.00	7.00	47.00	47.00	48.00	47.33	NA	NA	NA	NA
PQ2	J15	8.68E+04	249.00	522.00	0.12	13.00	3.00	36.00	39.00	31.00	35.33	2.00	4.00	3.00	10.00
PQ2	J15	8.68E+04	249.00	522.00	0.12	13.00	6.00	34.00	32.00	37.00	34.33	3.00	6.00	4.00	16.00
PQ2	J15	8.68E+04	249.00	522.00	0.12	13.00	9.00	32.00	40.00	36.00	36.00	3.00	7.00	4.00	12.00
PQ2	J15	8.68E+04	249.00	522.00	0.12	13.00	12.00	37.00	31.00	37.00	35.00	2.00	5.00	3.00	8.00
PQ2	J15	8.68E+04	249.20	522.20	0.32	16.00	6.00	28.00	25.00	27.00	26.67	3.00	6.00	4.00	18.00
PQ2	J15	8.68E+04	249.20	522.20	0.32	16.00	3.00	28.00	24.00	27.00	26.33	2.00	5.00	3.00	14.00
PQ2	J15	8.68E+04	249.20	522.20	0.32	16.00	9.00	27.00	26.00	26.00	26.33	3.00	5.00	4.00	14.00
PQ2	J15	8.68E+04	249.20	522.20	0.32	16.00	12.00	24.00	25.00	27.00	25.33	3.00	6.00	4.00	16.00
PQ2	J15	8.68E+04	250.20	523.20	1.04	54.00	12.00	31.00	32.00	33.00	32.00	4.00	12.00	6.00	NA
PQ2	J15	8.68E+04	250.20	523.20	1.04	54.00	9.00	34.00	35.00	37.00	35.33	4.00	12.00	6.00	20.00
PQ2	J15	8.68E+04	250.20	523.20	1.04	54.00	6.00	38.00	38.00	38.00	38.00	4.00	12.00	6.00	36.00
PQ2	J15	8.68E+04	250.20	523.20	1.04	54.00	3.00	33.00	35.00	35.00	34.33	4.00	12.00	6.00	NA
PQ2	J15	8.68E+04	253.70	526.70	1.78	122.00	9.00	32.00	32.00	32.00	32.00	4.00	10.00	6.00	24.00

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APPENDIX 2: DATA BASE FOR ZIRCALOY-2 PRESSURE TUBES

P02	J15	8.68E+04	253.70	526.70	1.78	122.00	12.00	30.00	31.00	31.00	30.67	4.00	10.00	6.00	20.00
P02	J15	8.68E+04	253.70	526.70	1.78	122.00	3.00	30.00	30.00	30.00	30.00	4.00	12.00	6.00	20.00
P02	J15	8.68E+04	253.70	526.70	1.78	122.00	6.00	31.00	32.00	33.00	32.00	4.00	10.00	6.00	16.00
P02	J15	8.68E+04	265.00	538.00	2.09	221.00	9.00	19.00	19.00	19.00	19.00	4.00	20.00	7.00	NA
P02	J15	8.68E+04	265.00	538.00	2.09	221.00	6.00	19.00	19.00	20.00	19.33	4.00	20.00	7.00	NA
P02	J15	8.68E+04	265.00	538.00	2.09	221.00	3.00	18.00	18.00	19.00	18.33	4.00	16.00	6.00	NA
P02	J15	8.68E+04	272.30	545.30	2.14	289.00	12.00	17.00	17.00	17.00	17.00	4.00	18.00	7.00	NA
P02	J15	8.68E+04	272.30	545.30	2.14	289.00	9.00	17.00	17.00	18.00	17.33	4.00	8.00	8.00	18.00
P02	J15	8.68E+04	272.30	545.30	2.14	289.00	6.00	18.00	19.00	19.00	18.67	4.00	8.00	8.00	24.00
P02	J15	8.68E+04	272.30	545.30	2.14	289.00	12.00	17.00	18.00	19.00	18.00	3.00	8.00	6.00	16.00
P02	J15	8.68E+04	286.50	559.50	2.03	412.00	3.00	17.00	17.00	17.00	17.00	3.00	8.00	6.00	12.00
P02	J15	8.68E+04	286.50	559.50	2.03	412.00	3.00	37.00	39.00	40.00	38.67	10.00	30.00	16.00	NA
P02	J15	8.68E+04	286.50	559.50	2.03	412.00	6.00	51.00	53.00	56.00	53.33	10.00	30.00	24.00	NA
P02	J15	8.68E+04	286.50	559.50	2.03	412.00	9.00	46.00	47.00	49.00	47.33	8.00	24.00	12.00	NA
P02	J15	8.68E+04	286.50	559.50	2.03	412.00	5.00	52.00	57.00	58.00	55.67	8.00	36.00	20.00	NA
P02	J15	8.68E+04	291.70	564.70	1.79	477.00	12.00	23.00	23.00	24.00	23.33	6.00	12.00	10.00	30.00
P02	J15	8.68E+04	291.70	564.70	1.79	477.00	9.00	106.00	107.00	109.00	107.33	10.00	30.00	16.00	NA
P02	J15	8.68E+04	291.70	564.70	1.79	477.00	6.00	112.00	114.00	120.00	115.33	20.00	42.00	32.00	NA
P02	J15	8.68E+04	291.70	564.70	1.79	477.00	3.00	100.00	103.00	103.00	102.00	20.00	40.00	30.00	NA
P02	J15	8.68E+04	293.50	566.50	1.60	504.00	12.00	68.00	69.00	73.00	70.00	6.00	18.00	10.00	NA
P02	J15	8.68E+04	293.50	566.50	1.60	504.00	9.00	178.00	197.00	182.00	185.67	20.00	40.00	30.00	NA
P02	J15	8.68E+04	293.50	566.50	1.60	504.00	3.00	145.00	157.00	162.00	154.67	24.00	44.00	32.00	NA
P02	J15	8.68E+04	293.50	566.50	1.60	504.00	12.00	116.00	119.00	135.00	123.33	8.00	18.00	14.00	36.00
P02	J15	8.68E+04	295.50	568.50	0.88	555.00	6.00	164.00	157.00	160.00	160.33	30.00	54.00	40.00	NA
P02	J15	8.68E+04	295.50	568.50	0.88	555.00	3.00	158.00	161.00	159.00	159.33	20.00	34.00	26.00	NA
P02	J15	8.68E+04	295.50	568.50	0.88	555.00	12.00	214.00	210.00	220.00	214.67	18.00	36.00	30.00	NA
P02	J15	8.68E+04	295.50	568.50	0.88	555.00	9.00	211.00	205.00	214.00	210.00	40.00	54.00	50.00	NA
P02	J15	8.68E+04	295.70	568.70	0.62	569.00	6.00	203.00	201.00	191.00	198.33	34.00	44.00	40.00	NA
P02	J15	8.68E+04	295.70	568.70	0.62	569.00	6.00	189.00	189.00	186.00	188.00	24.00	46.00	40.00	NA
P02	J15	8.68E+04	295.70	568.70	0.62	569.00	3.00	187.00	186.00	186.00	186.33	20.00	34.00	28.00	NA
P02	J15	8.68E+04	295.70	568.70	0.62	569.00	9.00	176.00	184.00	192.00	184.00	34.00	46.00	40.00	NA
P02	J15	8.68E+04	296.10	569.10	0.40	581.00	12.00	202.00	210.00	204.00	205.33	14.00	26.00	20.00	NA
P02	J15	8.68E+04	296.10	569.10	0.40	581.00	5.00	NA	NA	NA	NA	34.00	44.00	40.00	NA
P02	J15	8.68E+04	296.10	569.10	0.40	581.00	12.00	210.00	212.00	214.00	212.00	14.00	36.00	18.00	NA
P02	J15	8.68E+04	296.10	569.10	0.40	581.00	6.00	155.00	156.00	161.00	157.33	24.00	44.00	36.00	NA
P02	J15	8.68E+04	296.10	569.10	0.40	581.00	3.00	165.00	168.00	169.00	167.33	20.00	40.00	30.00	NA
P02	J15	8.68E+04	296.30	569.30	0.00	617.00	6.00	82.00	84.00	84.00	83.33	16.00	24.00	18.00	NA
P02	J15	8.68E+04	296.30	569.30	0.00	617.00	9.00	79.00	82.00	87.00	82.67	8.00	16.00	14.00	24.00
P02	J15	8.68E+04	296.30	569.30	0.00	617.00	3.00	84.00	87.00	88.00	86.33	8.00	16.00	12.00	20.00
P02	J15	8.68E+04	296.30	569.30	0.00	617.00	12.00	84.00	83.00	85.00	84.00	8.00	14.00	12.00	20.00
P02	K13	8.68E+04	281.20	554.20	2.11	363.80	12.00	47.00	50.00	46.00	47.67	NA	NA	NA	NA
P02	K13	8.68E+04	281.20	554.20	2.11	363.80	6.00	62.00	67.00	60.00	63.00	NA	NA	NA	NA
P02	K13	8.68E+04	281.20	554.20	2.11	363.80	9.00	68.00	70.00	68.00	68.67	NA	NA	NA	NA
P02	K13	8.68E+04	281.20	554.20	2.11	363.80	3.00	49.00	47.00	47.00	47.67	NA	NA	NA	NA
P02	V09	8.68E+04	294.00	567.00	1.54	509.50	9.00	76.00	NA	NA	76.00	16.00	30.00	24.00	NA
P02	V09	8.68E+04	294.00	567.00	1.54	509.50	6.00	77.00	NA	NA	77.00	18.00	30.00	24.00	NA
P02	V09	8.68E+04	294.00	567.00	1.54	509.50	12.00	71.00	NA	NA	71.00	6.00	18.00	12.00	NA
P02	V09	8.68E+04	294.00	567.00	1.54	509.50	3.00	69.00	NA	NA	69.00	8.00	20.00	14.00	NA

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APPENDIX 3

TABLE 1

ZIRCALOY 2 PRESSURE TUBE CORROSION RATES BETWEEN 250-300°C BASED ON LINEAR REGRESSION(1) OF LnR VS 1/T(2)

Unit			Pickering 1		Pickering 2	
Clock Position			6 o'clock	12 o'clock	6 o'clock	12 o'clock
Intercept (LnA)			37.83	10.77	29.50	16.67
Slope (B)			-19.17	-4.81	-14.43	-7.65
Standard Deviation (σ)			0.90	0.47	0.56	0.40
Correlation Coefficient (R^2)			76%	18%	72%	46%
Oxidation Rate (R)(3) (Microns/hr) ($\times 10^5$)	250°C	Average	3.24	4.82	6.75	7.71
		95%	19.60	12.34	20.68	17.16
	275°C	Average	17.26	7.34	23.76	15.0
		95%	104.4	18.78	72.81	33.45
	300°C	Average	79.4	10.76	74.95	27.64
		95%	480.3	27.54	229.7	61.51

(1) Assuming linear relationship between Maximum Uniform Oxide Thickness and Effective Full Power Hours.

(2) High flux data only ($>1.5 \times 10^{13}$ n/cm^2*sec).

(3) Where $LnR = LnA - B/(T \times 10^{-3})$.

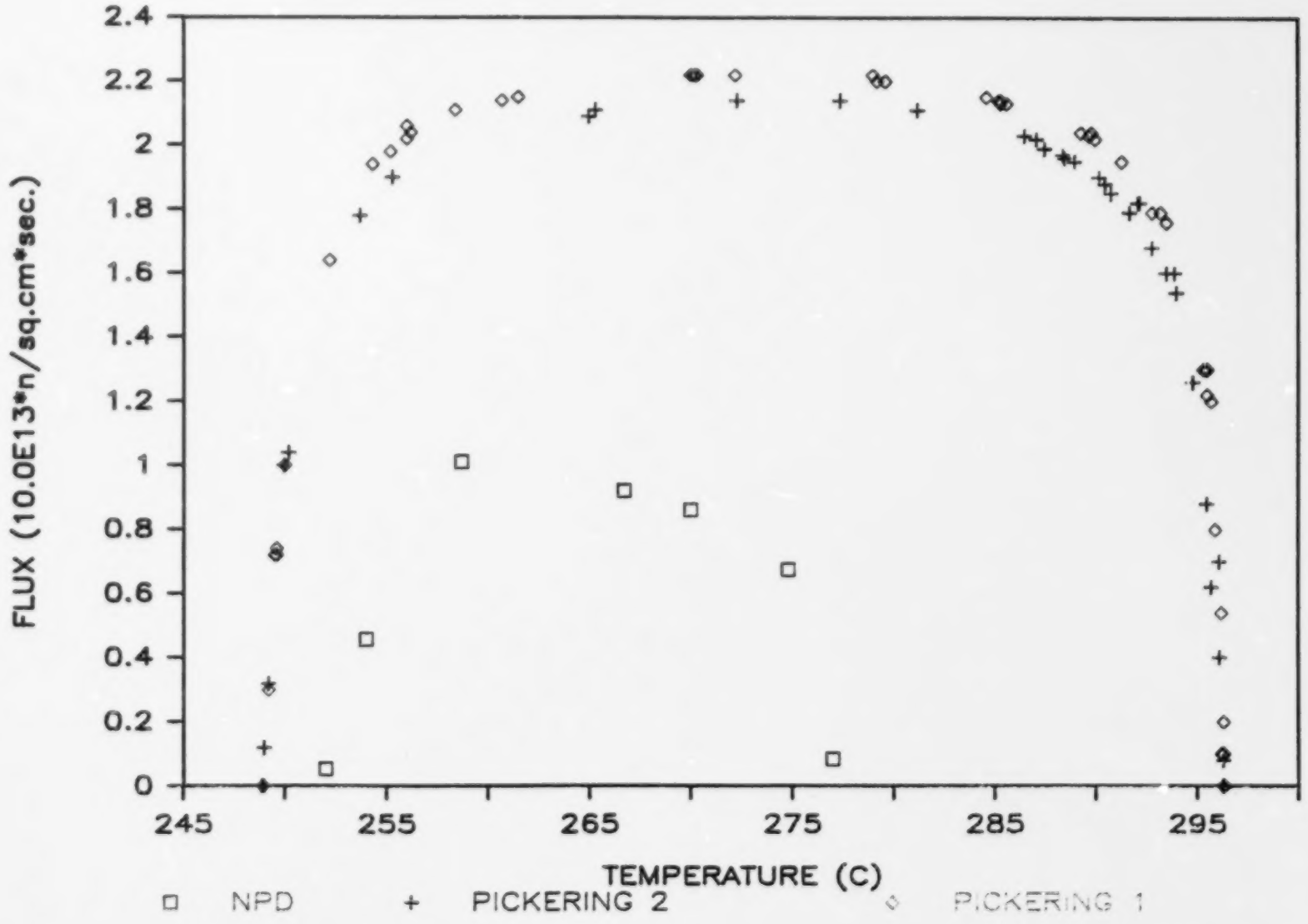
APPENDIX 3

TABLE 2

% THEORETICAL DEUTERIUM PICKUP FOR ZIRCALOY 2 PRESSURE TUBES FROM PICKERING UNITS 1 and 2

Unit	PT#	% Theoretical Pickup(1)	
		Mean	Standard Deviation (σ)
P1	A11	57	40
P1	G14	31	28
P1	G16	70	56
P1	G20	44	22
P1	K05	58	28
P1	K18	58	42
P2	A11	28	15
P2	G16	33	18
P2	J15	24	12
P2	V09	23	5
P2	G07	42	35

(1) Where 100% Theoretical Deuterium Pickup = 14 ppm/Micron oxide for a pressure tube (wall thickness ≈4 mm)



APPENDIX 3, FIGURE 1: FLUX AND TEMPERATURES FOR ALL AXIAL LOCATIONS OF MEASUREMENTS FOR ZIRCALOY-2 PRESSURE TUBES P1-G14,G16,G20,K05,K18/P2-G16,J15,V09/ NPD-G07.

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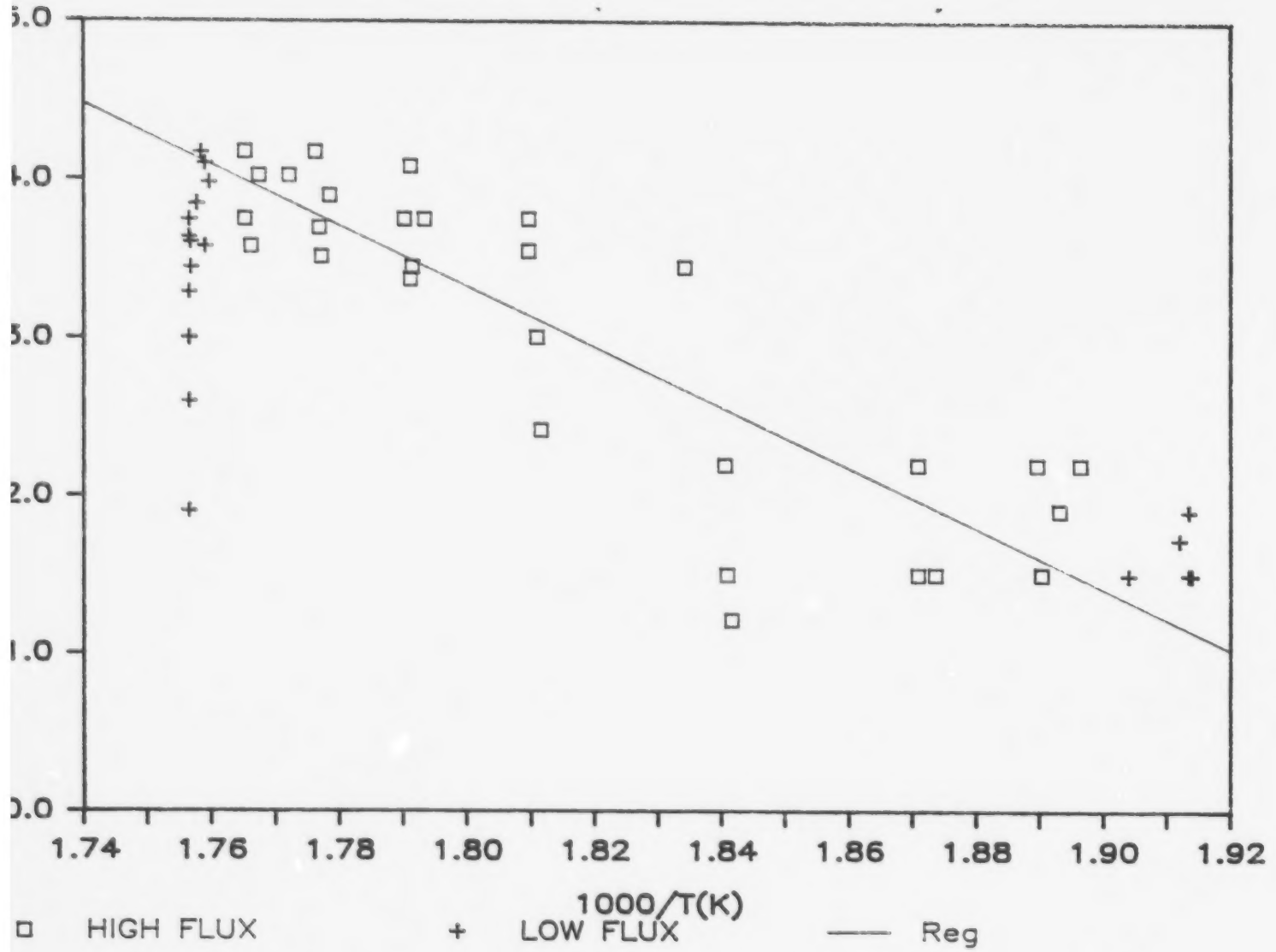
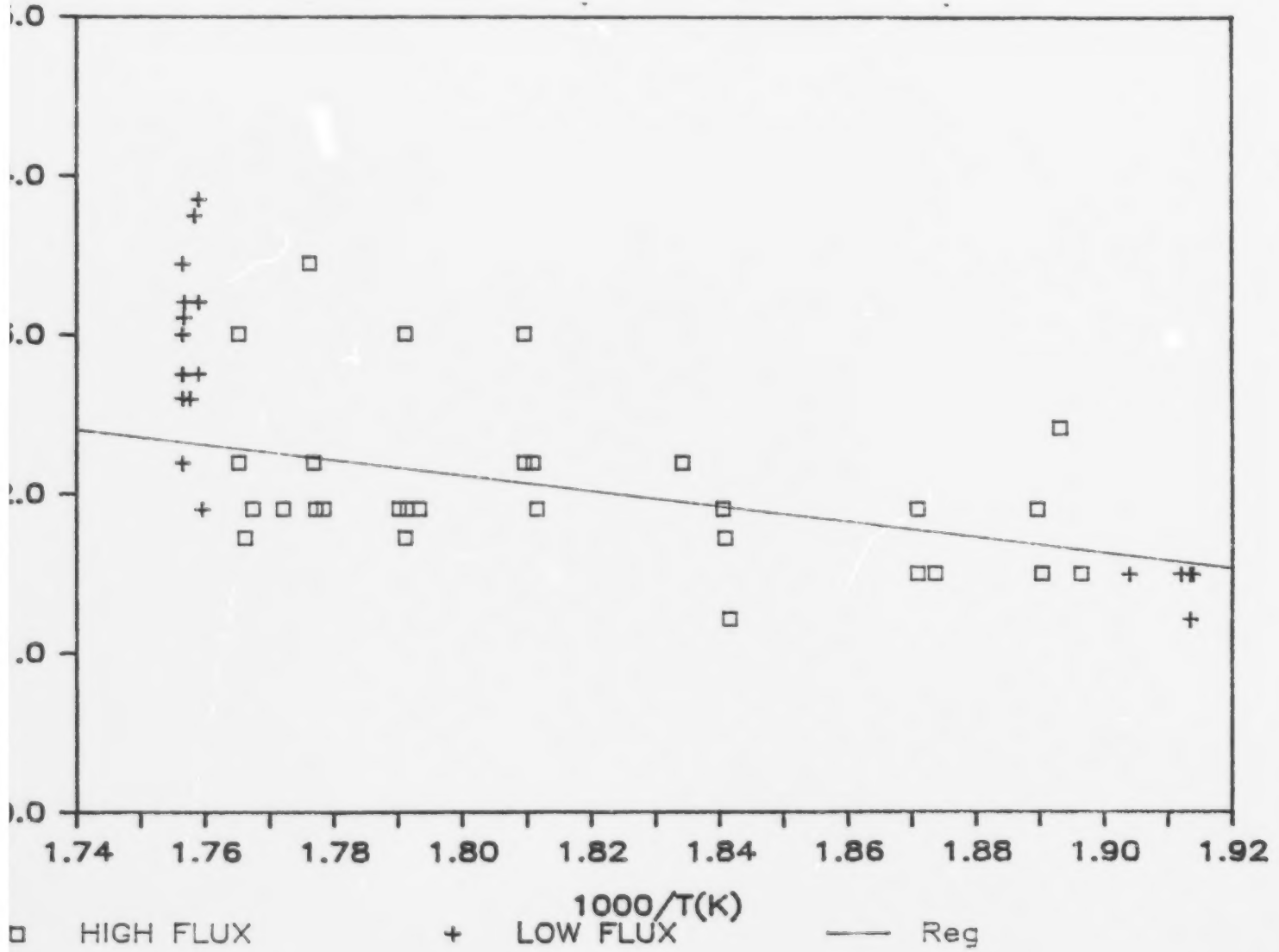
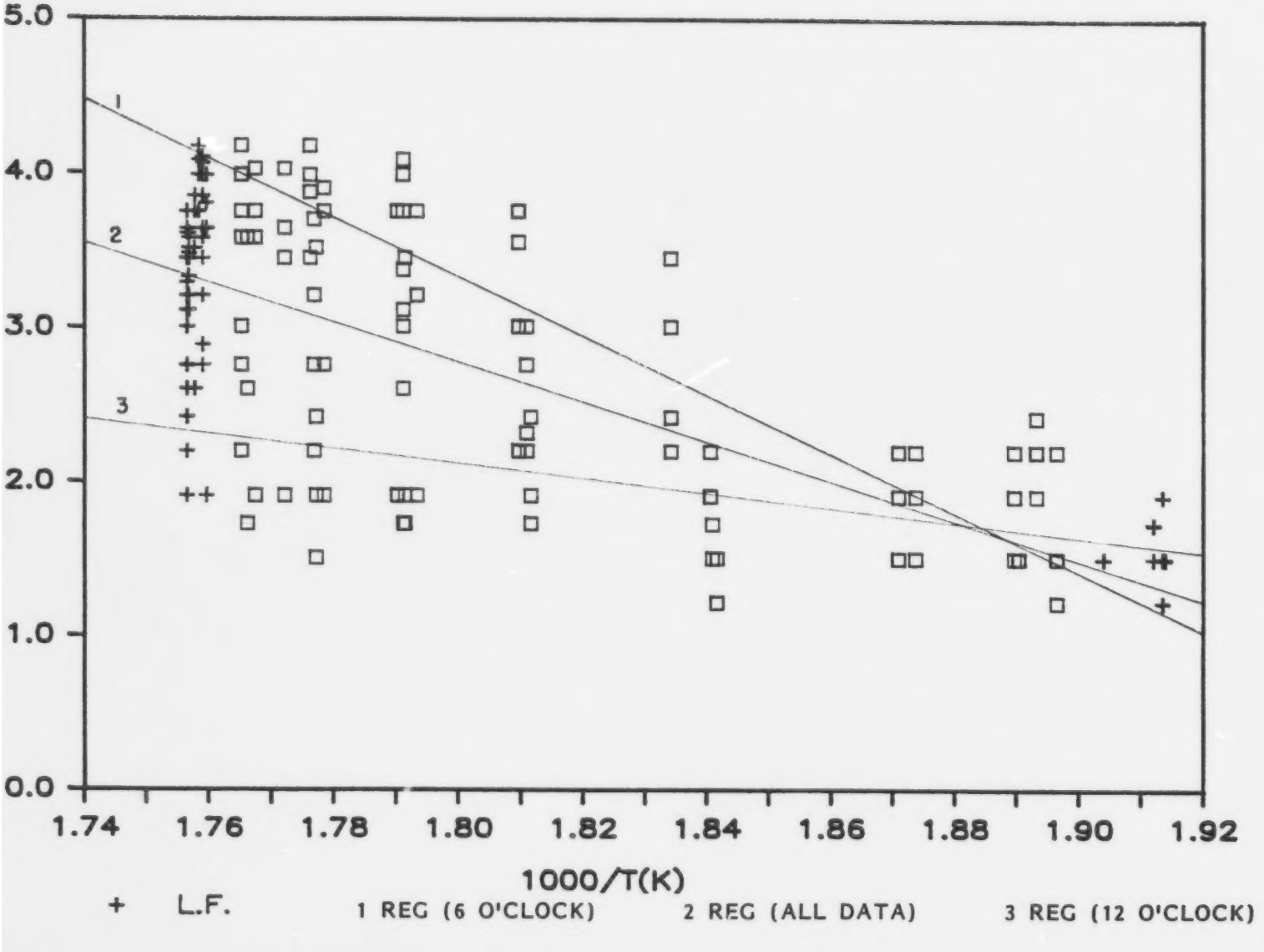


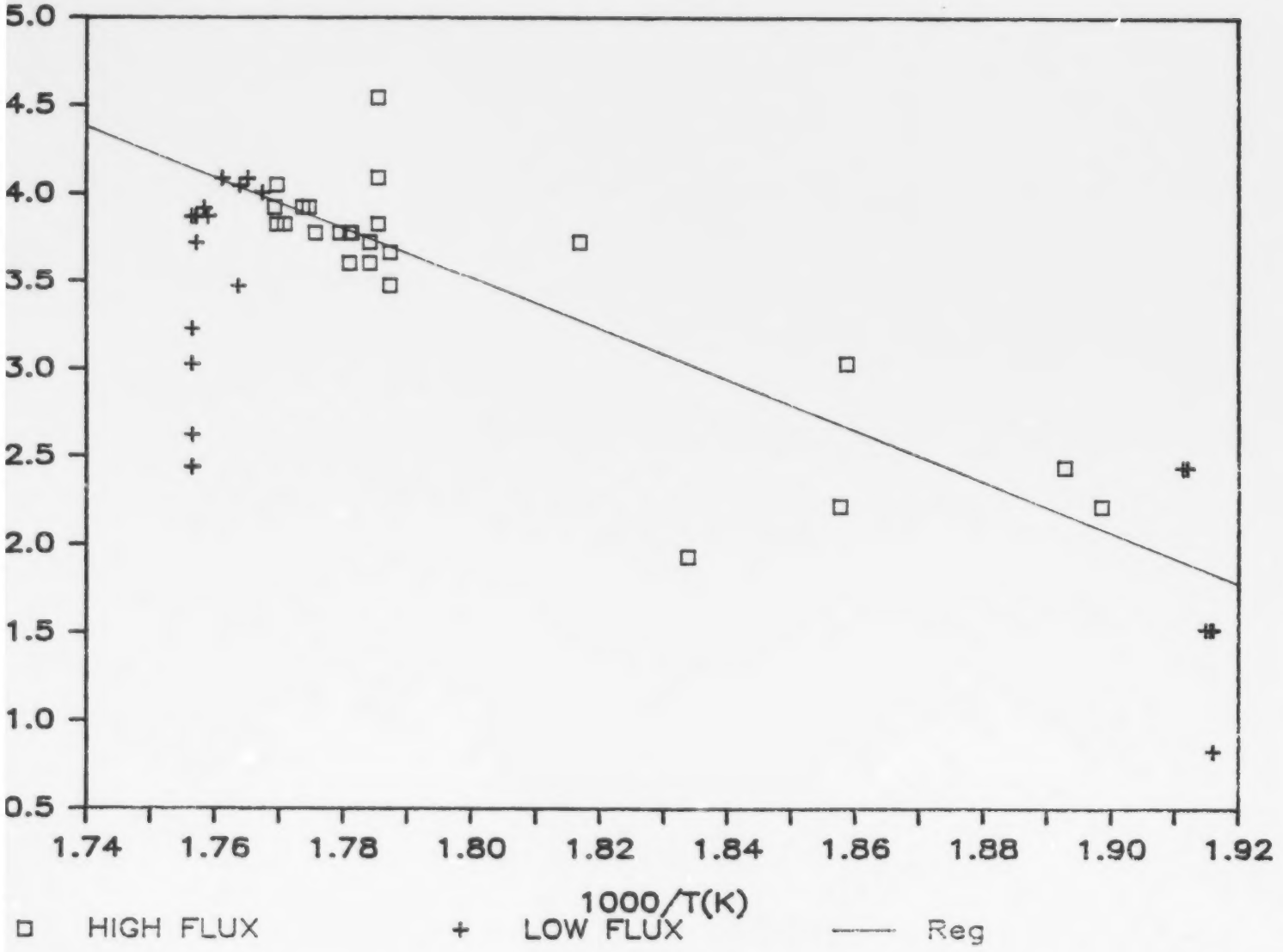
PENDIX 3, FIGURE 2a: LINEAR REGRESSION FIT OF HIGH FLUX ($>1.5X10^{13}$ n/cm^2*sec) DATA FOR LN MAXIMUM OXIDATION RATE VS 1000/T FOR ZIRCALOY-2 PRESSURE TUBES P1-G14, G16, G20, K05, K18. (6 O'CLOCK POSITION ONLY)



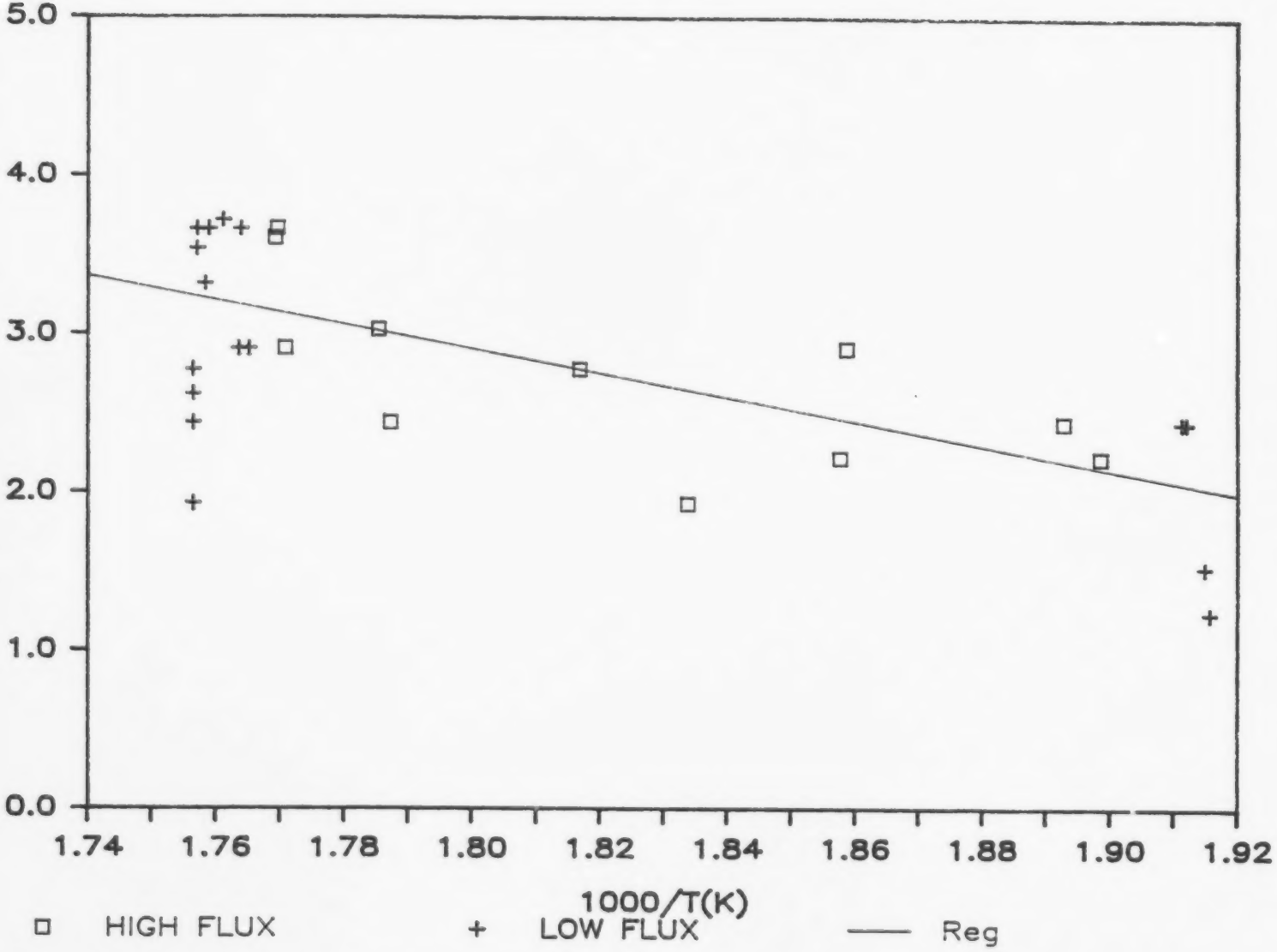
NDIX 3, FIGURE 2b: LINEAR REGRESSION FIT OF HIGH FLUX ($>1.5X10^{13}$ n/cm^{2}*sec) DATA FOR LN MAXIMUM OXIDATION RATE VS 1000/T FOR ZIRCALOY-2 PRESSURE TUBES P1-G14, G16, G20, K05, K18. (12 O'CLOCK POSITION ONLY)



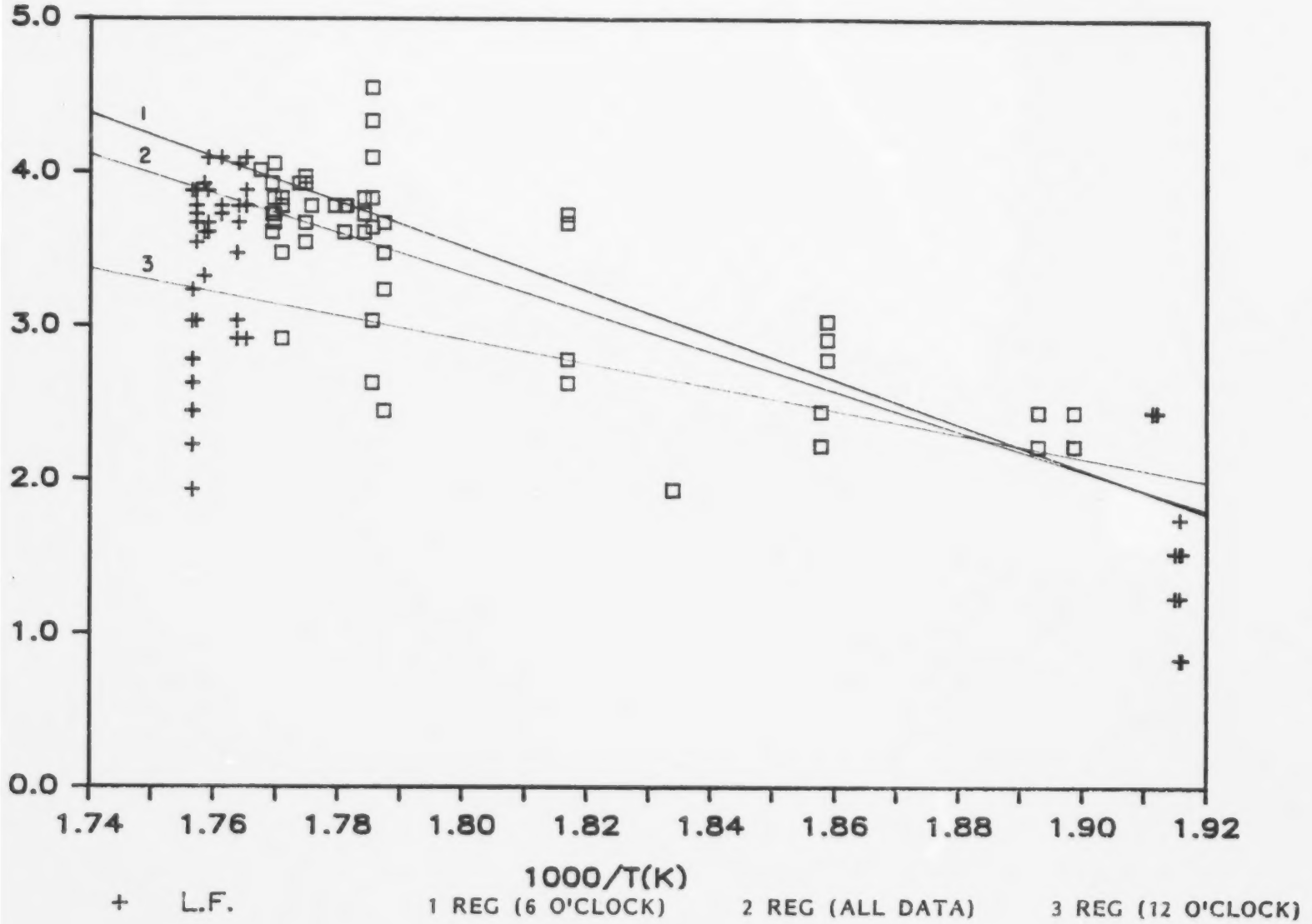
PENDIX 3, FIGURE 2c: COMPARISON OF LINEAR REGRESSION FITS FOR HIGH FLUX DATA FROM THE 6 & 12 O'CLOCK POSITIONS FOR LN MAXIMUM OXIDATION RATE VS 1000/T FOR ZIRCALOY-2 PRESSURE TUBES P1-G14,G16,G20,K05,K18.



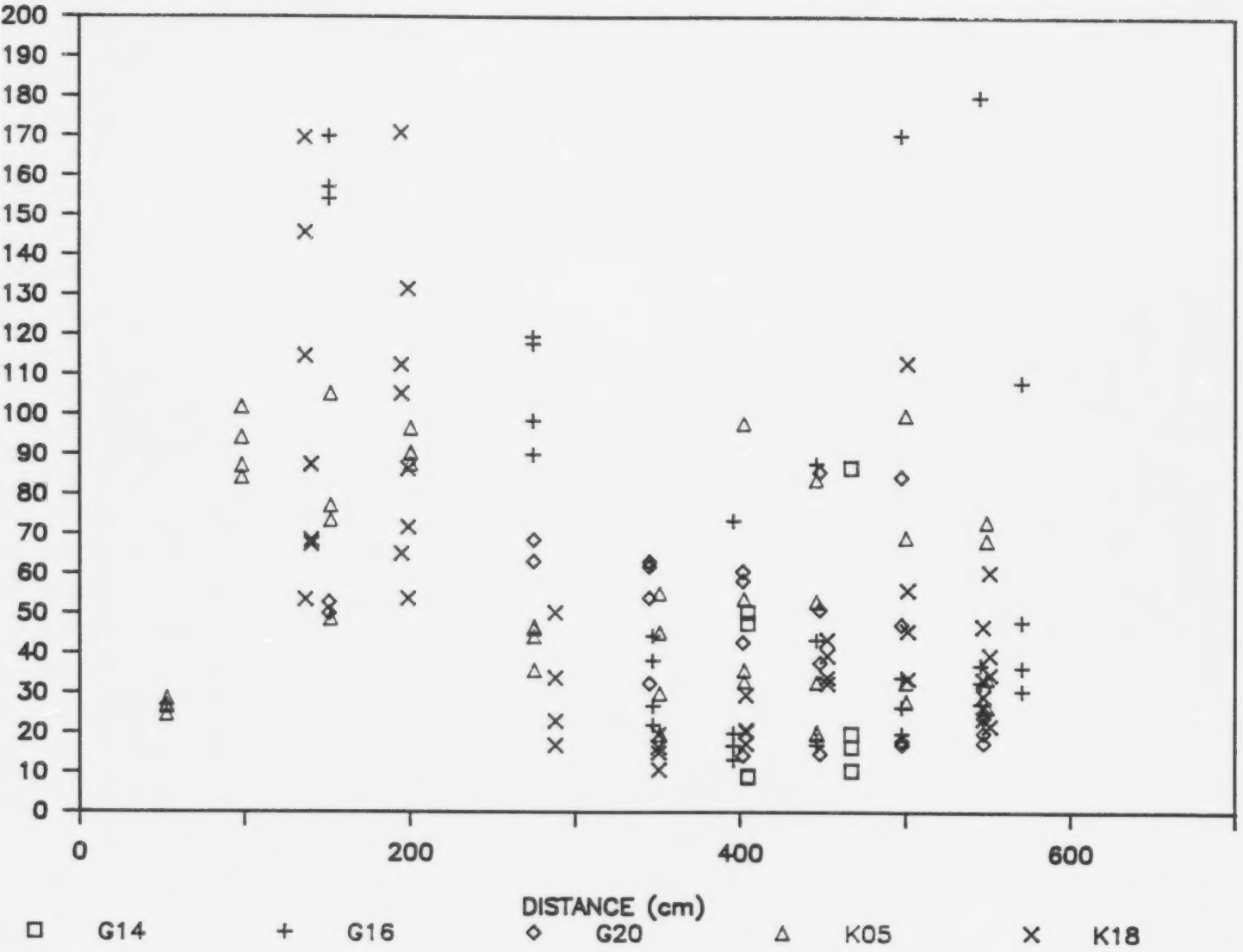
ENDIX 3, FIGURE 3a: LINEAR REGRESSION FIT OF HIGH FLUX ($>1.5X10^{13}$ n/cm^2*sec) DATA FOR LN MAXIMUM OXIDATION RATE VS 1000/T FOR ZIRCALOY-2 PRESSURE TUBES P2-G16, J15, V09. (6 O'CLOCK POSITION ONLY)



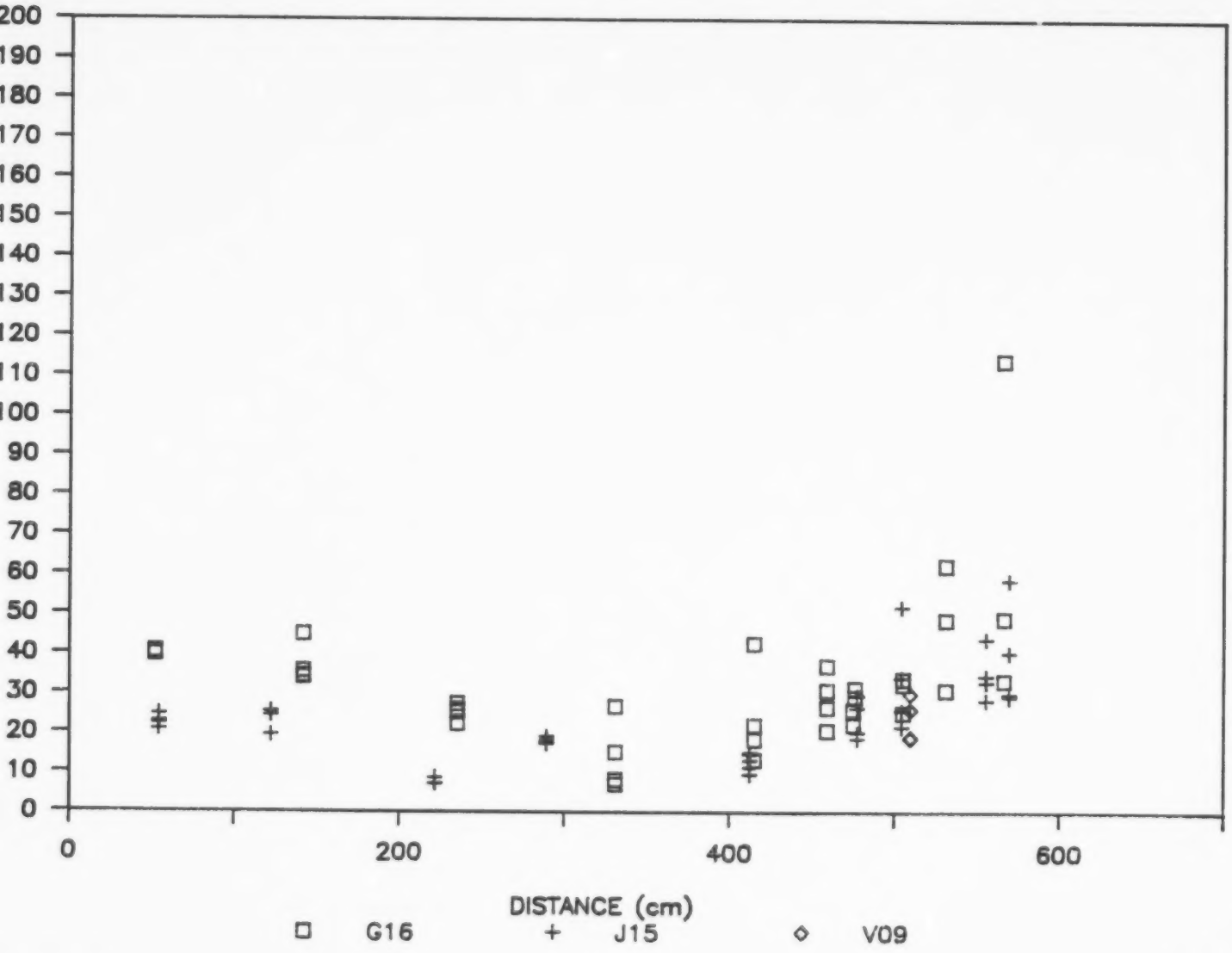
PENDIX 3, FIGURE 3b: LINEAR REGRESSION FIT OF HIGH FLUX ($>1.5X10^{13}$ n/cm^2*sec) DATA FOR LN MAXIMUM OXIDATION RATE VS 1000/T FOR ZIRCALOY-2 PRESSURE TUBES P2-G16, J15, V09.



PENDIX 3, FIGURE 3c: COMPARISON OF LINEAR REGRESSION FITS FOR HIGH FLUX DATA FROM THE 6 & 12 O'CLOCK POSITIONS FOR LN MAXIMUM OXIDATION RATE VS 1000/T FOR ZIRCALOY-2 PRESSURE TUBES P2-G16, J15, V09.



PPENDIX 3, FIGURE 4a: PERCENTAGE THEORETICAL DEUTERIUM PICKUP VS DISTANCE FROM INLET FOR ZIRCALOY-2 PRESSURE TUBES P1-G14,G16,G20,K05,K18. (EXCLUDING UP TO 50cm FROM PRESSURE TUBE ENDS)



PENDIX , FIGURE 4b: PERCENTAGE THEORETICAL DEUTERIUM PICKUP VS DISTANCE FROM INLET FOR ZIRCALOY-2 PRESSURE TUBES P2-G16, J15, V09 (EXCLUDING UP TO 50cm FROM PRESSURE TUBE ENDS)